# RECOVERY OF GOLD BY SINGLE STAGE DEEP FLUIDIZED BED, ION EXCHANGE AND CARBON TECHNIQUE

FINAL REPORT

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Recovery of Gold by Single Stage Deep Fluidized Bed,
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Recovery of Gold by Single Stage Deep Fluidized Bed,
Ion Exchange and Carbon Technique

## EXECUTIVE SUMMARY

Recovery of gold from aqueous gold containing solutions by carbon and ion exchange methods has been carried out. The use of Canmet single stage fluidized bed as a contactor device has been evaluated. Based upon the test results obtained, it is believed that strong base anionic resin can be considered as an adsorbent for unclarified heap leach type solutions obtained from placer type ores using Canmet single stage deep fluidized bed. The presence of dissolved base metal ions significantly reduces gold loading capacity. The use of i) potassium thio cyanate in di-methyl formamide and water or ii) Electro elution procedures offer alternatives to acid elution methods for recovering gold from loaded resin column.

Economic comparison of gold recovery from heap leach type solutions, without the presence of base metal ions, indicate the use of single stage deep fluidized bed ion exchange column with strong base resins to be higher than conventional activated carbon route. This is entirely due to the present cost of resin (IRA-400) tested as against the carbon cost.

Recovery of Gold by Single Stage Deep Fluidized Bed,
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## 1. INTRODUCTION

Carbon-In-Pulp (CIP) process is now widely applied in the major gold producing countries for the recovery of gold from pregnant leach solution. The process provides significant economic benefits over the Merrill-Crowe process.

More recently, the development of highly efficient separating devices as well as larger, more resistant ion exchange resins have led to the introduction of resin-in-pulp (RIP) processes. It has been suggested that the RIP process may have distinct advantages over the use of activated carbons particularly when fouling is a problem.

The next generation of gold recovery processes is likely to include continuous fluidized bed type adsorption process and a more economic desorption process. Such a system using ion exchange resins to recover elements such as uranium is well developed in the mineral industry. However, such multi-stage systems have complicated internals and control systems to regulate resin movement. In comparison, single-stage deep fluidized systems have the attraction of relatively simple engineering and have been proposed for the recovery of metals from solution.

Prior to the development of a gold recovery system as described above, it was necessary to evaluate the different exchange media available (i.e. activated carbons and ion exchange resins) to

determine the most suitable media. During Phase I of the project, results were obtained to evaluate both activated carbons and ion exchange resins in terms of gold adsorption and elution prior to conducting pilot scale studies on single stage deep fluidized bed. During Phase II of the project selected resins and carbons were evaluated for their suitability in pilot scale and technical and economic viability were assessed.

The present report includes results obtained from Phase I of the project; setting up of Canmet single stage deep fluidized bed column, evaluation of upto two carbons and resins for their performance in pilot scale. An economic evaluation of carbon vs. resin to recover gold from pregnant solution is also included.

## 2. BACKGROUND

The CIP technique was originally developed to by-pass the expensive counter current decantation (CCD) and filtration steps involved in the traditional Merril Crowe processing of gold ores.

Many publications have since indicated the advantages of CIP over the Merril Crowe procedure in terms of both operating and capital costs, particularly for low grade uses. DeMent and King (1) have estimated that the break-even point for CIP vs. Merril Crowe to be about 15 g/t head grade, with values above this favouring the later technique. Since most ores today contain less than 15 g/t gold content increasing interest is shown on CIP option to treat leach solutions.

A recent development in carbon adsorption technology has been the introduction of the carbon-in-leach (CIL) process whereby leaching and adsorption are carried out simultaneously. The CIL process offers the advantage of lower capital costs, since a separate adsorption section is unnecessary. Disadvantages in CIL result from decreased adsorption efficiency since pulp conditons must be maintained for favourable leaching performance rather than for carbon adsorption (2). There is little information available comparing CIL to CIP for identical ores, and so actual performance results are inconclusive as to the cost advantages in either process.

Some important developments in CIP technology have recently been made which have greatly improved the process and brought about its wider acceptance in the gold industry. In particular, improvements have been made in pulp agitation (better mixing at lower shear) carbon/pulp separation (highly efficient EPAC screens) and carbon elution (high temperature Zadra Anglo American and Micron Research techniques).

The development of the Mintek EPAC (equalized-pressure air cleaned) screening systems to separate pulp and carbon have been particularly important since one of the major problems in CIP processes has been the lack of efficient separation of the two streams. This problem has been a particular limiting factor for RIP (Resin in Pulp) processes where the resin size is smaller than that of activated carbons. With the advent of the new EPAC screens it is expected that pulp/resin separation will not be a problem in future CIP and RIP circuits.

Although resin-in-pulp technology is not new to the mining industry (it has been used for many years in the processing of uranium ores), application on gold and silver circuits have been limited. As a result of the new screening technology discussed earlier and the development of larger, more resistant resins, a greater interest in RIP technology is evident. In Russia, RIP circuits seem to be more prominent than CIP operations for the recovery of gold and silver. In the western world, however, such developments have only reached the pilot stage.

The RIP process has a number of advantages over CIP, including superior loading kinetics, higher adsorption capacity, simple elution and, most importantly, elimination of fouling by organic species or clay.

The drawbacks in RIP techniques compared to CIP include decreased selectivity for gold, smaller size and low density. The performance of resins in plant operations is relatively unknown.

Both resins and carbon are likely to play key roles in future gold recovery processes. Although less is known about the performance of resins in gold ores, the ion exchange process is well developed for other metals. Some of the technology designed for the recovery of these other materials will inevitably be applied to gold ore processing.

Future gold recovery processes are likely to utilize innovative technologies borrowed from other metal industries.

In particular, the use of continuous fluid bed type adsorption processes for treating liquors and slurries will be more prominent in the gold industry. These have become relatively well developed over the years and offer the advantages of low resin inventory as well as the ability to treat unclarified solutions. However, the multi-stage systems in current use are complicated.

The recent development of the single-stage deep fluidized bed system has combined the advantages of fluid bed technology with a relative simple design. This method so far has been tested with ion exchange resins only. However, it would require only slight modifications to adapt the technology for use with activated carbon. It is foreseeable that the fluidized bed approach will be at the forefront of the next generation of gold recovery processes.

With these objectives the present research program is carried out, and the results are used in selecting the media for gold removal from leach liquors using a contactor such as single stage deep fluidized bed column.

# 3. BENCH SCALE CARBON AND RESIN SCREENING TESTS

## 3.1 Carbon Testing

### 3.1.1 Adsorption

It is believed that gold in cyanide leach solutions exists as cyanide complex, $Au(CN)_2^-$. The adsorption of gold from such leach solutions by carbon is claimed to take place by either in a form chemically derived from aurocyanide, AuCN, reduction of gold to metallic state during adsorption, or typically as in an ion-exchange mechanism. Extensive work by NIM and Anglo American Research Laboratories seem to support the former two theories. In all these cases however, the physical properties of the chosen carbon and the chemistry of leach solutions will have significant effects on the gold adsorption. To understand such effects, several commercially available carbon samples (Calgon PCB, Calgon GRC 22, Norit R2020, Norit R2515, Haycarb TRT5, Haycarb XTY) were tested for their adsorption capacity and adsorption rate.

Prior to conducting adsorption tests, details on the physical characteristics of each carbon were obtained in Table I. Hardness measurements were supplied by the manufacturers and refer to ASTM D.3802-79, standard test methods for ball pan hardness of activated carbon. The listed value is the percentage retained on the smaller mesh size after testing.

Attritioning tests were conducted on all carbons prior to their use in adsorption tesing. Attritioning was conducted on 50 g lots of dry carbon with 100 ml of distilled water in a 500 ml bottle.

The bottle was rotated end over end for 24 hours at 46 rpm. The values listed are the percent retained from the smaller mesh size after attritioning. Bulk density, pore volume, particle size, moisture content and pH values were experimentally obtained.

Table I
Carbon Physical Characteristics

| | Calgon GRC 22 | Calgon PBC | Haycarb TRT 5 | Haycarb XTY | Norit R2020 | Norit R2515 |
|---|---|---|---|---|---|---|
| Mesh size | 6x16 | 6x16 | 8x16 | 8x16 | 2x4 mm | 1.4x4 mm |
| Hardness % retained | 98.0 | 92.0 | 99.0 | 98.8 | 99.0 | 100.0 |
| Attritioning % retained | 90.7 | 97.0 | 94.2 | 95.3 | 95.7 | 90.1 |
| Bulk Density g/cc | 0.47 | 0.44 | 0.56 | 0.49 | 0.52 | 0.50 |
| Pore Volume cc/g | 0.72 | 0.72 | 0.49 | 0.69 | 0.65 | 1.00 |
| Moisture % | 2.8 | 2.8 | 3.5 | 5.2 | 1.3 | 1.4 |
| pH | 9.7 | 9.8 | 9.9 | 9.9 | 10.6 | 10.6 |

To determine the effects of changes in process parameters in adsorption the loading conditions were changed at three levels (Table II). The carbon was conditioned in a 5% (volume) hydrochloric acid solution for 24 hours, washed and dried for 16 hours prior to use in the test program.

These tests were carried out independently with only one factor being changed at a time. Testing was conducted with 500 ml of a nominal 35 ppm Au solution in a 2 L vessel with three carbon additions: 0.1, 0.5, and 1.0 g. The carbon loading and adsorption kinetics for all carbons at each test condition are shown in Tables III and IV.

Typical statistical analysis on the correlation of loading characteristics at 20° C, pH 10.5, 0.1% cyanide concentration and 400 rpm agitation (Table V) showed linear correlationship between adsorption capacity and pore volume. Other physical parameters failed to exhibit any correlation.

Under the test conditions, decreasing the agitation rate resulted in a lower carbon loading and seem to indicate "Liquid Film Diffusion" as controlling mechanism. For loading from dilute solution this seems feasible. Under the test conditions maximum carbon loadings were obtained at pH 10.5 and ambient temperatures.

Based upon the total ranking values obtained, Calgon PCB, Calgon GRC 22 and Haycarb XYT (Table V) displayed superior performance in terms of adsorption kinetics and adsorption capacity.

Table II

Test Parameters for Carbon Adsorption

| Variable | Levels | |
|---|---|---|
| Temperature | 20°C | 6°C 35°C |
| pH | 10.5 | 8.8 12.3 |
| Cyanide Concentration | 0.1% | 0.5% |
| Agitation | 400 rpm (all carbon in suspension) | 200 rpm (approx. 20% carbon in suspension) |

Table III

Adsorption Capacity of Commercially Available
Carbon After 24 Hours Loading

| | CARBON | LOADING |
|---|---|---|
| 1. | Norit R2515 | (19.0 kg/tonne) |
| 2. | Calgon GRC 22 | (18.9 kg/tonne) |
| 3. | Calgon PBC | (18.8 kg/tonne) |
| 4. | Haycarb XTY | (18.7 kg/tonne) |
| 5. | Norit R2020 | (18.5 kg/tonne) |
| 6. | Haycarb TRT 5 | (17.4 kg/tonne) |

Table IV
Adsorption Kinetics of Commercially Available Carbon

| CARBON | m |
|---|---|
| 1.Norit R2515 | (m = 1.29) |
| 2.Calgon PBC | (m = 1.07) |
| 3.Calgon GRC 22 | (m = 0.96) |
| 4.Haycarb XTY | (m = 0.83) |
| 5.Norit R2020 | (m = 0.72) |
| 6.Haycarb TRT 5 | (m = 0.54) |

Ranking (m = slope of ln (xo/x) vs t)

Table V

Effect of Changes in Process Variables on Carbon Adsorption Loading in kg/tonne

| Test Conditions Examined | Calgon PCB | Norit R2020 | Calgon GRC-22 | Norit R2515 | Haycarb TRT5 | Haycarb XTY |
|---|---|---|---|---|---|---|
| Baseline Test | 26.43(1) | 19.63(4) | 26.36(2) | 16.55(5) | 12.59(6) | 24.87(3) |
| High Cyanide | 24.05(1) | 13.25(6) | 24.00(2) | 20.54(4) | 15.84(5) | 23.04(3) |
| High Temperature | 17.70(4) | 13.64(6) | 18.62(2) | 19.31(1) | 14.12(5) | 18.35(3) |
| Low Temperature | 22.25(1) | 13.13(6) | 21.87(2) | 17.26(4) | 15.44(5) | 21.49(3) |
| Low pH | 23.76(1) | 16.60(6) | 23.51(2) | 19.73(4) | 18.20(5) | 22.04(3) |
| High pH | 22.85(1) | 13.15(6) | 22.46(2) | 17.86(5) | 17.95(4) | 21.22(3) |
| Low Turbulence | 19.97(1) | 12.19(6) | 19.58(2) | 17.47(4) | 14.59(5) | 19.20(3) |
| TOTAL: | (10) | (40) | (14) | (27) | (35) | (27) |

- Rankings are shown in parenthesis( )

### 3.1.2 Elution Tests

Two methods of carbon elution were examined, the caustic cyanide elution (Zadra) and electro-desorption. Based upon the loading performance and to include a pellitized carbon, Calgon PCB, Calgon GRC 22 and Norit 2515 were chosen for elution performance comparison.

### 3.1.3 Zadra Type Elution

The tests were carried out by varying temperature, CN content and caustic concentration at three levels (Table VI). Elution was carried out in a 1/2" stainless steel column with a downflow of hot caustic cyanide solutions at 10 BV/hour. Elution performance under the tested conditions for the three carbons is shown in Table VI. Higher cyanide, higher caustic and higher temperature proved to be most effective. Higher caustic and cyanide concentrations resulted in higher rates of desorption.

### 3.1.4 Electro Desorptions

As an alternative to Zadra type elution, elctro elution of loaded carbon was tested. Elution of gold presumably by electrochemical oxidation followed by the deposition of dissolved gold was attempted. The three selected carbons after loading were eluted at an emf 2.5V, temperature (80, 90, 100$^{o}$C), caustic concentration (0.5, 1, 5%) and cyanide concentration (0.05, 0.1, and 1.0%). The results are shown in Table VII. The test results showed higher gold elution efficiency at higher temperature and lower cyanide and caustic contents.

Table VI
Effect of Process Variables on Gold Elution %

| Test Variable | Baseline Condition | Test Conditions |
|---|---|---|
| Temperature | 100°C | 88°C, 120°C |
| NaCN Content | .1% | 0.05%, 0.5% |
| NaOH Content | 1% | 0.5%, 5% |

| Carbon: | Norit 2515 | | | Calgon PCB | | | Calgon |
|---|---|---|---|---|---|---|---|
| GRC | | | | | | | |
| Time (hrs.): | 1/2 | 1 | 3 | 1/2 | 1 | 3 | 1/2 |
| 1 3 | | | | | | | |
| Condition: | | | | | | | |
| Low temp. | 1.43 | 2.96 | 10.40 | 1.28 | 3.16 | 13.71 | 1.58 |
| 3.19 15.91 | | | | | | | |
| Low NaCN | 13.54 | 18.07 | 24.93 | 11.96 | 16.66 | 29.32 | 16.41 |
| 22.26 35.13 | | | | | | | |
| Low NaOH | 9.29 | 11.54 | 20.81 | 8.98 | 10.41 | 24.11 | 10.65 |
| 13.85 30.44 | | | | | | | |
| Baseline | 12.49 | 18.33 | 49.68 | 11.16 | 21.64 | 62.72 | 15.54 |
| 26.31 77.62 | | | | | | | |
| High temp | 19.83 | 25.91 | 65.64 | 32.73 | 39.77 | 72.62 | 25.09 |
| 35.13 73.16 | | | | | | | |
| High NaCN | 25.31 | 28.60 | 65.80 | 31.71 | 40.94 | 75.90 | 36.37 |
| 44.25 81.51 | | | | | | | |
| High NaOH | 13.06 | 18.43 | 51.15 | 20.92 | 30.80 | 83.33 | 22.01 |
| 28.26 79.22 | | | | | | | |

## Table VII
## Carbon Electrodesorption Results

| TEST CONDITIONS | | | GOLD DISTRIBUTION (% Au Available) | | |
|---|---|---|---|---|---|
| SOLUTION | | TEMPERATURE | CARBON | SOLUTION | STEEL WOOL |
| NaCN + NaOH% | | °C | | | |
| CARBON | Low | 80 | 54.8 | 45.2 | 0 |
| | High | 80 | 51.3 | 37.5 | 11.2 |
| | Low | 90 | 15.1 | 52.7 | 32.2 |
| CALGON | High | 90 | 30.8 | 52.0 | 16.3 |
| GRC 22 | Low | 100 | 7.6 | 73.6 | 18.8 |
| | High | 100 | 29.7 | 34.8 | 35.5 |
| | Baseline | 100 | 13.9 | 17.1 | 69.0 |
| | Low | 80 | 60.5 | 20.8 | 18.7 |
| | High | 80 | 71.3 | 19.6 | 9.1 |
| | Low | 90 | 44.3 | 29.4 | 26.3 |
| | High | 90 | 62.3 | 25.7 | 12.0 |
| CALGON | Low | 100 | 16.2 | 13.5 | 70.3 |
| PCB | High | 100 | 39.7 | 31.8 | 28.5 |
| | Baseline | 100 | 19.1 | 10.5 | 70.4 |
| | Low | 80 | 74.7 | 13.4 | 11.8 |
| | High | 80 | 57.0 | 16.1 | 22.9 |
| | Low | 90 | 55.7 | 21.5 | 22.8 |
| | High | 90 | 71.8 | 24.2 | 4.0 |
| NORIT | Low | 100 | 40.5 | 20.1 | 39.4 |
| 2515 | High | 100 | 52.6 | 34.9 | 12.5 |
| | Baseline | 100 | 41.6 | 14.8 | 43.6 |

## 3.2 Resin Evaluations

### 3.2.1 Loading

The application of anion exchange resins for recovering gold from cyanide solutions has been an accepted technology in the Soviet Union and has been practised with a resin-in-pulp circuit.

Aurocyanide complex $Au(CN)_2^-$ from aqueous leach solution can be recovered by ion exchange methods and the following reactions may prevail:

$$R_3NX^- + Au(CN_2)^- \rightleftharpoons \underset{S}{R_3N^+ Au(CN)_2^-} + X^-$$

(strong base resin)

$$\underset{S}{R_2NH^+X^-} + Au(CN)_2^- \rightleftharpoons \underset{S}{R_2NH^+ Au(CN)_2^-} + X^-$$

(weak base resin);
S = resin phase

An evaluation of the above equilibria indicates the $Au(CN)_2^-$ complex can be adsorbed by strong base resins at a wider range of pH compared to weak base resin.

To determine the adsorption characteristics of ion exhange resins and to compare their performance to that of activated carbons, six commercially available resins were selected for study. A summary of the selected resins and brief descriptions of the resin are shown in Table VI.

Stir tank loading tests were conducted with resin in the sulphate form. Test conditions such as NaCN content, gold content, temperature, pH and added metal ion concentrations were varied independently to provide data regarding their effect on resin loading. Details of various resin conditions and results of these investigations are shown in Table X. The results showed strong base resins (IRA-400) to provide loading up to 158 g/L w.s.r. while weak base resins (Ionac A305) showed resin loading of about 3.7 g/L w.s.r. It is believed that weak base resins in the free base form are unchanged and they require protonation for aurocyanide loading to occur. Protonation is affected by lowering the pH of the feed to less than the pK of the tertiary amine functional group.

Testwork done in South Africa on a number of commercially available weak base ion exchange resins has shown that the maximum adsorption of anionic species from solution occurred at pH values 7-9.

Breakthrough curves obtained for gold loading, indicate the loadings of strong base resins of IRA 400 at 158 g/L w.s.r. as maximum (Figures 1, 2, 3, and 4).

The above analysis of the reaction-pathways for gold absorption would explain the higher loading capacity of strong base resins at the baseline pH value (10.2).

It also explains the reason for the greater sensitivity of weak base resins to changes in the solution pH. While both varieties showed higher absorption capacities at lower pH values, the effect was more profound on the weak base resins, with an average increase of 11.8% gold recovery in going from pH 12.3 to 8.7.

Loading tests conducted with added interfering ions also showed the higher affinity of strong base resins for dissolved anionic species. Although both resin types showed decreased gold loading with the addition of Cu, Fe and Pb ions to solution, the effect was most noticeable on the strong base resins. In addition, the recovery of copper during these tests was found to be higher for the strong base resins than for the weak base resins.

The effect of gold concentration was less quantifiable than that for the other ionic species noted above.

For both the stirred tank and column tests gold loading was found to be indirectly related to the size of the resin beads. Smaller resin sizes resulted in faster reaction kinetics and thus higher equilibrium loading capacities, as shown by tests conducted on Dowex 21K -20+40 mesh and -16+20 mesh resin beads. This would indicate that surface area plays a significant role in the rate of gold loading. In addition, the loading of other cationic species (i.e. Cu) is increased with decreasing resin particle size, thus indicating a potential problem area in attempting to increase gold loading by using smaller resin beads.

For both the strong and weak base ion exchange resins the absorption reaction is enhanced at increased temperatures. This is in direct contrast with the results obtained for activated carbons, where increased temperatures resulted in decreased gold loading may be due to the partial redissolution of aurocyanide by the hot cyanide liquor.

As with the activated carbons, gold loading on to the ion exchange resins was hindered by the presence of excess cyanide in solution. The probable cause for this occurrence in ion exchange resins is likely to be due to a reversal in the absorption reaction caused by the presence of a high concentration of anions (i.e. $CN^-$) in solution.

### 3.2.2 Elution

Based upon the loading performances of the resins, it was concluded that strong base resins Amberlite IAR-400, Dow 21K (16-20M) and Dow 21K (20-40M) and weak base resins Duolite A7 and Ionac A305 be chosen for detailed elution studies. The results are shown in Tables X and XI.

As shown in Tables X and XI, strong base elution efficiencies improved with the lowering of temperature; elution of weak base resins improved with increased caustic levels and temperature.

The main result of the elution studies in this program is the confirmation of previously documented evidence that weak base resins may be eluted more efficiently than the strong base resins by adjusting the pH of eluants.

The result is that although weak base resins show poorer loading characteristics than strong base resins, elution is much simpler and more complete; a definite advantage in terms of process design considerations.

Improvement in strong base resin elution characteristics was not achieved by increasing the cyanide or zinc concentrations of the eluant. This would indicate that the rate of this elution reaction can be only marginally increased by increasing the availability of either zinc or cyanide in solution.

The result is not totally unexpected since removal of the aurocyanide from strong base resins using zinc cyanide follows the reaction:

$$2\ {-}^{+}NR_3Au(CN)_2^{-} + Zn(CN)_4^{2-} \rightleftharpoons ({-}NR^{+}{}_3)_2\ Zn(CN)_4^{2-} + 2Au(CN)_2^{-}$$

Aurocyanide on the resin is displaced by zinc cyanide. Thus, the addition of zinc and cyanide to the eluant must be in such a ratio as to favour maximum formation of the $Zn(CN)_4^{2-}$ complex. An excess of either zinc or cyanide species alone would not result in increased gold recovery.

An increase in the performance of strong base resin elution was achieved by decreasing the eluant temperature to 5°C and is consistent with the results obtained under loading conditions.

The weak base ion exchange resins were eluted using a dilute caustic solution and thus the reaction follows the equation:

$$-^{+}NR_2HAu(CN)_2^{-} + OH^{-} \rightleftharpoons -NR_2 + H_2O + Au(CN)_2^{-}$$

Considering this, it could be concluded that weak base resin elution is dependent upon the availability of $OH^{-}$ ions in solution. The results from the test program would tend to substantiate this theory. Of the process variables tested (temperature, cyanide addition and caustic concentration), only caustic concentration hence had a significant effect on resin elution under the tested conditions.

## 4.0 PHASE I ACTIVITY CONCLUSIONS

Tests conducted to evaluate the effect of physical parameters of carbon on carbon adsorption indicated during phase I, a strong correlation of pore volume to the adsorption capacities. Amongst the chosen carbon samples Carbon PCB, Calgon GRC 22, Norit 2515 and Haycarb XTY showed superior loading efficiencies, The results obtained on the effect of agitation showed the likelihood of adsorption to take place by a liquid film diffusion mechanism. Similiarly strong base resins showed higher loading performance under the tested conditions. Based upon these results up to two representative carbons and resins were considered for evaluation using CANMET single stage deep fluidized bed for evaluation.

Table VIII
Summary of Ion Exchange Resins Tested

| Resin | Type |
|---|---|
| Amberlite IRA 400 (16-50m) | granular, strong base anion resin |
| Sybron Ionac SR3 (16-50m) | macroporous chelating |
| Sybron Ionac SR3 (10-40m) | granular, mixed intermediate |
| Dow XSF 4132 | chelating anion resin |
| Dowex 21k (16-20m) | strong base anion resin |
| Dowex 21k (20-40m) | strong base anion resin |
| Duolite A7 (16-50m) | macroporous weak base anion resin |

Table IX
Stir Tank Resin Loading (% Gold Recovered)

| Resin | Test Condition | | | | | |
|---|---|---|---|---|---|---|
| | Low Cyanide | High Cyanide | Low pH | High pH | Low Temp | High Temp |
| Amberlite IRA 400 (16-50m) | 40.1 | 37.4 | 41.2 | 39.1 | 27.7 | 52.9 |
| Sybron Ionac SR3 (16-50m) | 29.2 | 19.0 | 36.0 | 9.4 | 20.7 | 29.9 |
| Sybron Ionac A305 (10-40m) | 16.4 | 9.9 | 12.0 | 13.3 | 10.0 | 17.5 |
| Dow XFS 4132 | 6.6 | 4.8 | 11.7 | 7.3 | 4.3 | 7.7 |
| Dowex 21K (16-20m) | 18.7 | 18.1 | 21.9 | 20.3 | 11.9 | 24.3 |
| Dowex 21K (20-40m) | 38.9 | 38.0 | 36.6 | 34.2 | 25.2 | 50.8 |
| Duolite A7 (16-50m) | 25.6 | 18.1 | 33.9 | 10.3 | 17.3 | 29.2 |

Resin Loading Test Conditions:

| | pH | Cyanide Content (% NaCN) | Temperature (°C) | Solution Gold Content (ppm) |
|---|---|---|---|---|
| High | 12.3 | 0.50 | 35 | 100 |
| Baseline | 10.2 | 0.10 | 22 | 33 |
| Low | 8.7 | 0.05 | 6 | 10 |

Table IX (Cont'd.)
Stir Tank Resin Loading (% Gold Recovered)

| | Test Condition | | | |
|---|---|---|---|---|
| Resin | Low Gold Content | High Gold Content | Low Interfering Metal Addition | High Interfering Metal Addition |
| Amberlite IRA 400 | 38.5 | 37.1 | 33.4 (17.5)* | 20.2 (15.2) |
| Sybron Ionac SR3 | 29.8 | 29.4 | 20.3 (0) | 20.2 ( 5.4) |
| Sybron Ionac A305 | 14.4 | 17.9 | 6.6 ( 7.1) | 6.2 ( 4.9) |
| Dow XFS 4132 | 6.7 | 0 | 7.4 ( 1.3) | 10.1 (10.3) |
| Dowex 21K (16-20m) | 19.2 | 23.4 | 19.1 (14.9) | 12.1 ( 9.2) |
| Dowex 21K (20-40m) | 37.5 | 40.3 | 32.9 (27.9) | 20.8 (12.0) |
| Duolite A7 | 29.8 | 25.0 | 21.4 ( 6.5) | 18.8 ( 2.7) |
| Total Metal Addition: | | | 0.2 gpl Cu<br>2.5 ppm Fe<br>trace Pb | 1.8 gpl Cu<br>68 ppm Fe<br>2 ppm Pb |

* numbers in brackets are % Cu recovered

Table X

Strong Base Resin Stirred Tank Elution Tests

| | Au Eluted | | |
|---|---|---|---|
| | Amberlite IRA 400 | Dowex 21K 16-20M | Dowex 21K 2040 |
| Low Temperature (50°C) | 51.1 | 53.5 | 71.2 |
| High Temperature (35°C) | 15.5 | 11.7 | 23.9 |
| Low Zn Concentration (5 gpL Zn) | 35.4 | 21.6 | 51.4 |
| Low CN (3:1 Excess) | 30.5 | 27.0 | 47.2 |
| High CN (7:1 Excess) | 33.0 | 33.7 | 56.5 |
| Baseline | 31.7 | 23.7 | 51.0 |

Base Conditions:

2 1/2 ml resin
100 ml solution
20 gpL Zn
5:1 ratio CN to Zn for $Zn(CN)_4^{2-}$
25 gpL NaOH
22°C

Table XI
Elution Under Varied Conditions
Weak Base Elution - % Gold Eluted

| | Duolite A7 | Ionac A305 |
|---|---|---|
| Low Caustic 1 gpL | 40.0 | 8.7 |
| High Caustic 10 gpL | 70.1 | 28.6 |
| Low Temperature 6°C | 48.7 | 23.1 |
| High Temperature (1) 35°C | 75.4 | 24.4 |
| High Temperature (2) 80°C | 78.9 | 23.0 |
| Cyanide Addition 1 gpL NaCN | 52.0 | 29.4 |
| Baseline | 59.3 | 23.4 |

2.5 mL resin, 25 mL solution, 5 minutes contact

Loading of resins approximately 2.5 gpL w.s.r.

Baseline elution condition - 5 gpL caustic
22°C

FIGURE 1

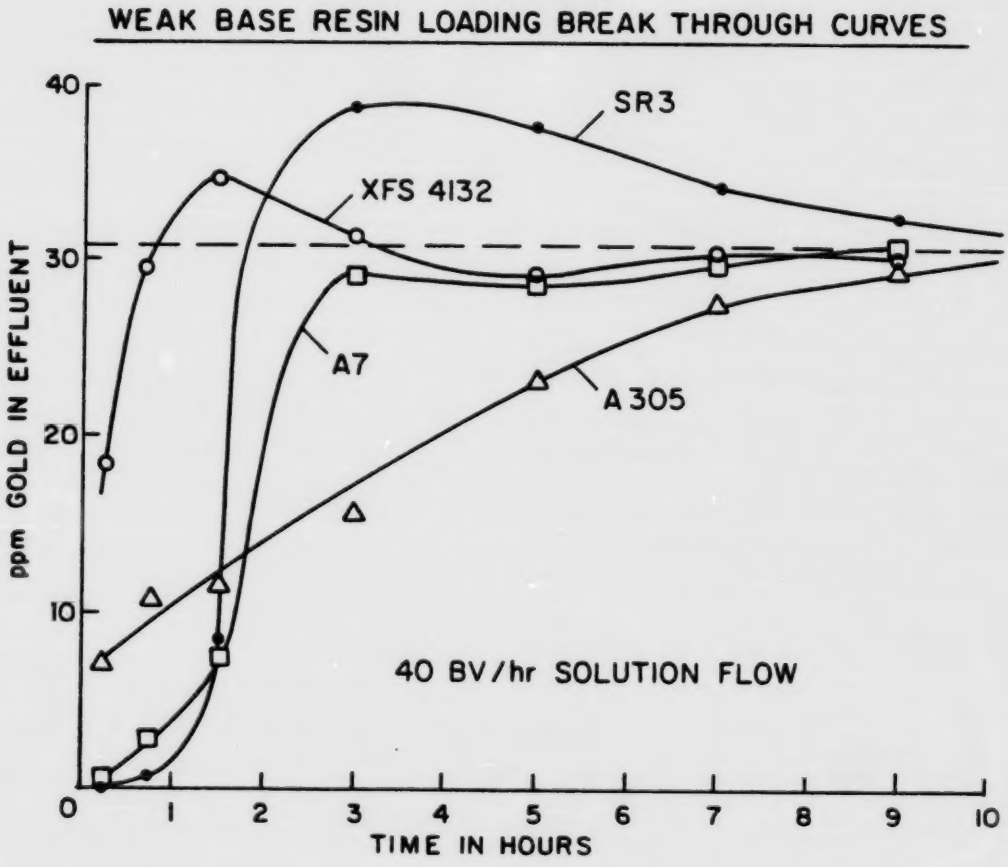

WEAK BASE RESIN LOADING BREAK THROUGH CURVES
SR3
XFS 4132
A7
A 305
40 BV/hr SOLUTION FLOW
ppm GOLD IN EFFLUENT
TIME IN HOURS
0
10
20
30
40
1
2
3
4
5
6
7
8
9
10

FIGURE 2

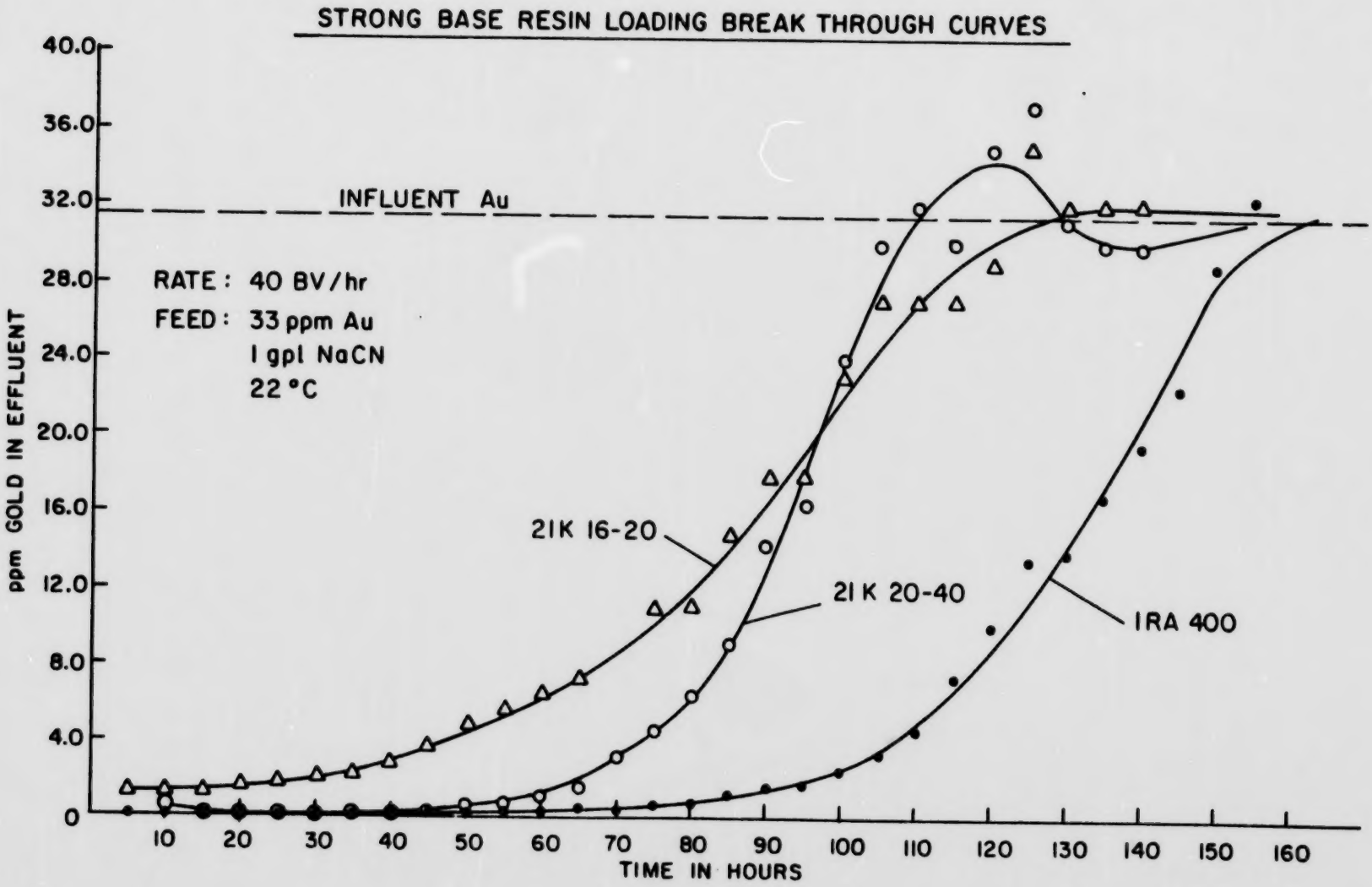

STRONG BASE RESIN LOADING BREAK THROUGH CURVES
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0
ppm GOLD IN EFFLUENT
INFLUENT Au
RATE : 40 BV/hr
FEED : 33 ppm Au
1 gpl NaCN
22 °C
21K 16-20
21K 20-40
IRA 400
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
TIME IN HOURS

FIGURE 3

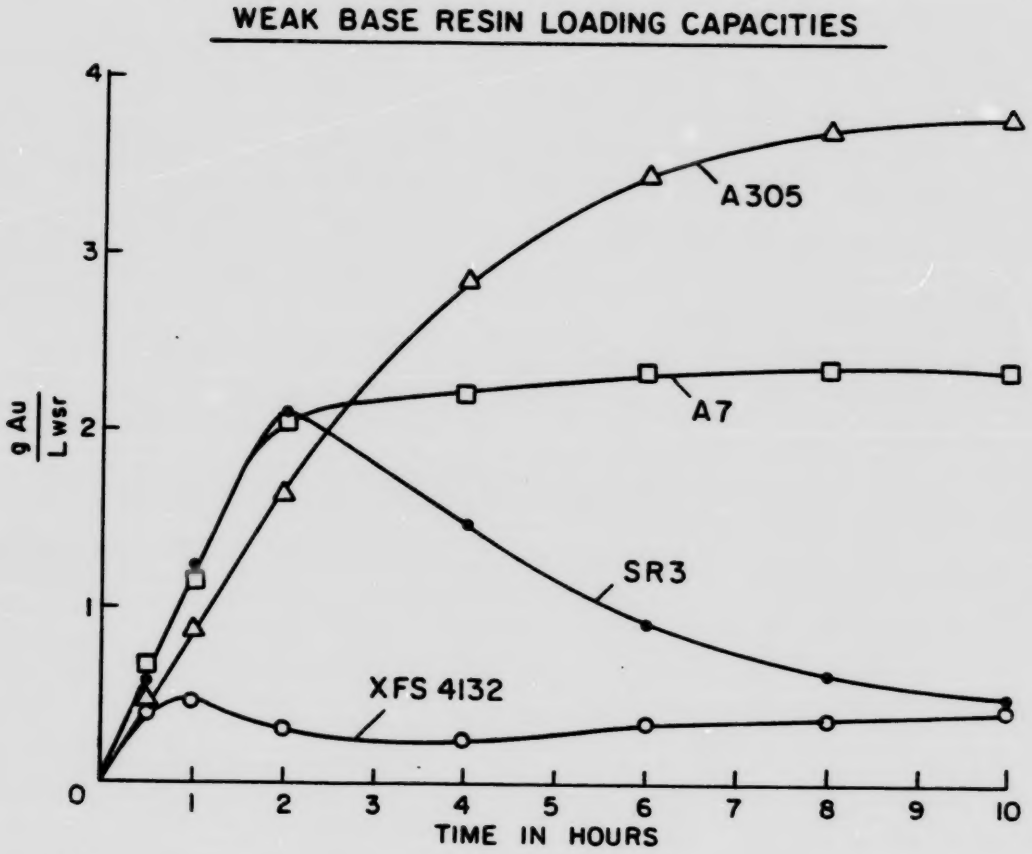
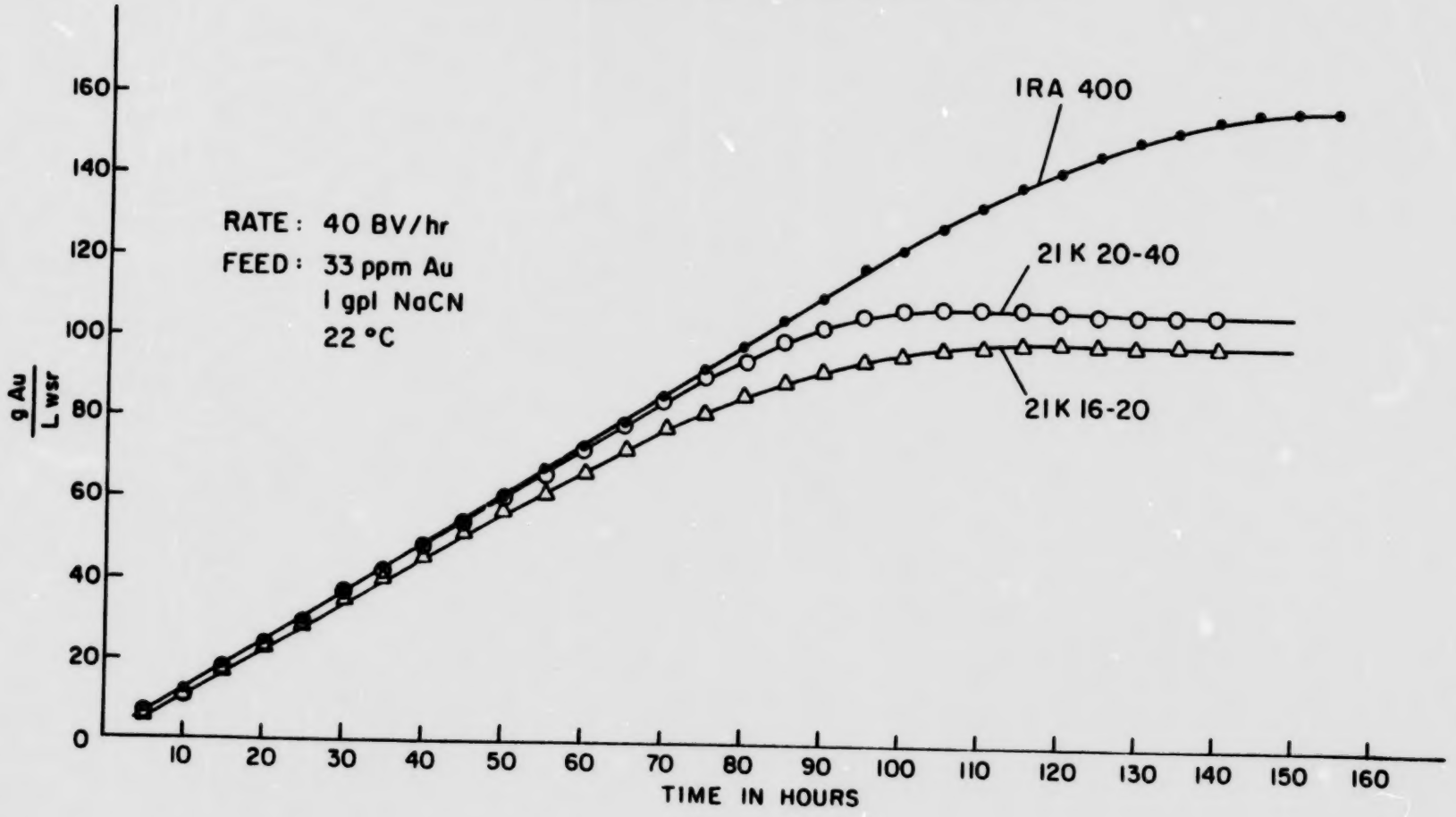

WEAK BASE RESIN LOADING CAPACITIES
g Au / L wsr
A305
A7
SR3
XFS 4132
TIME IN HOURS
0
1
2
3
4
5
6
7
8
9
10

FIGURE 4

## STRONG BASE RESIN LOADING CAPACITIES



## 5. CONSTRUCTION AND OPERATION OF CANMET SINGLE STAGE DEEP FLUIDIZED CONTINUOUS ION EXCHANGE COLUMN

### Assembly

The ORF single stage Fluidized Bed Ion Exchange Column was built according to the descriptionprovided by Prudhomme and Lucas in the CANMET Report 79.9(7). The general layout of the continuous ion exchange column is shown in Figure 4. The set up was made within a 1.3 $m^2$ tower made from 3.3 cm diameter steel tubing. The height of the tower is 6.1 m. Working platforms for storage tanks and pumps were installed at appropriate intervals. The tower is anchored to a wall.

The loading column is constructed of 51 mm diameter Kimax glass tubes, 2.44 m long supported by the tower column. Above the adsorption column is a sealed receiver for resin feed. The details of the absorption column construction and sealed resin feed receiver are shown in Figure 5.

The elution column is 3.12 m high, made up of a 51 mm diameter by 2.08 m Kimax glass tube surmounted by a 102 mm diameter by 0.96 m section. A wash column, 51 mm in diameter by 1.22 m high is located below the elution column.

### 5.1 Operation of the Pilot Plant

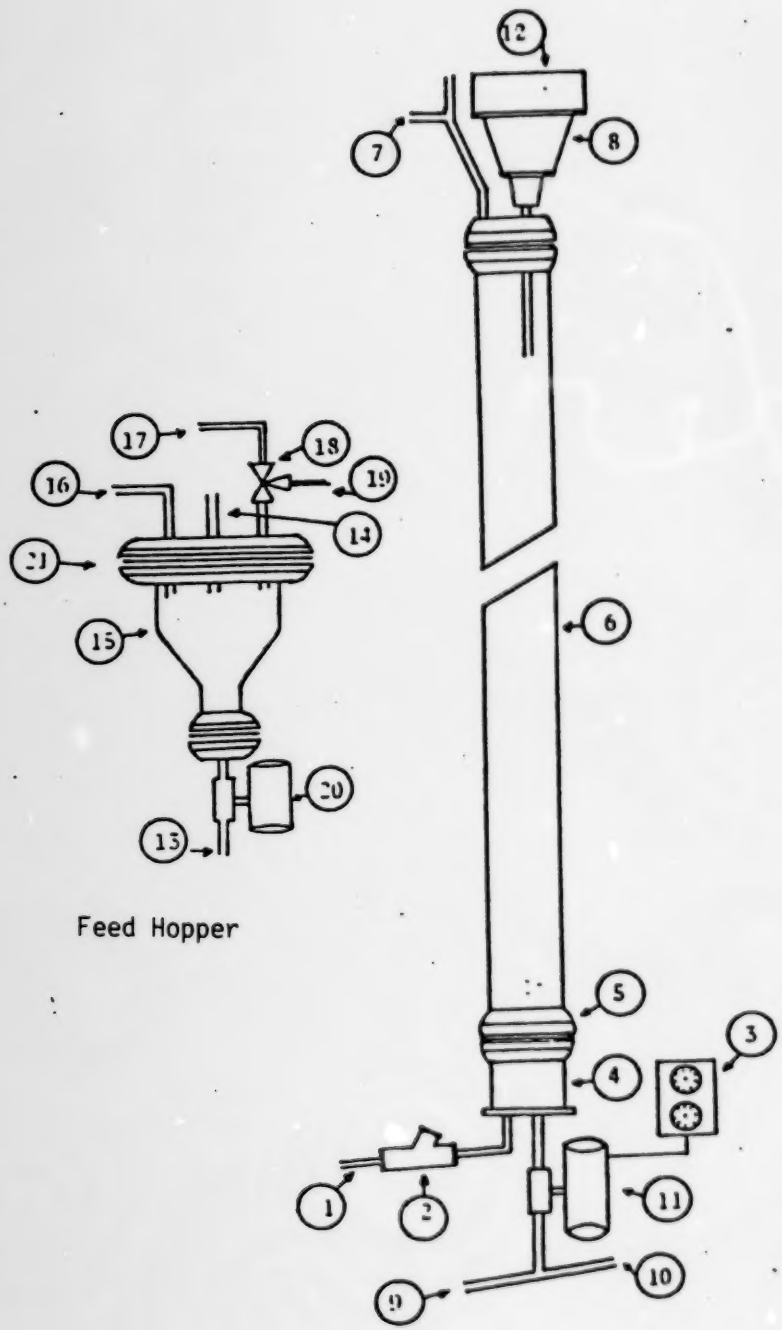
The loading column is operated with a metered upflow solution, sufficient to fluidize the bed and maintain a desired height. At set intervals a calculated increment of loaded resin is transferred to the elution column. The resin increment per minute is equal to V/60T where V is the volume of resin in the extraction column and T is resin retention time in hours, given by the breakthrough in a static run. Eluate solution transfers the loaded resin to the top of the elution column.

Water is metered into the base of the wash column and flows upward into the elution column where it meets the eluant and dilutes it to a desired strength. The state of the resin in this column is slightly expanded. A photo electric cell with a light source placed over the top of the elution column maintains the desired heights. Upon interruption of the light sensor by transfer of the loaded resin, a similar amount of resin is moved from the base of the wash colum. Resin then moves over the elution column through a 19 mm diameter pipe directly into the wash column.

The resin feed receiver vessel on top of extraction column is a sealed unit to which compressed air, vacuum and water can be applied. A solenoid valve provides compressed air and vacuum. The photoelectric cell actuates the valve which allows a vacuum to transport resin feed and water to the receiver vessel until the resin level in the elution column reaches a predetermined set point. A timer regulates the volume of resin removed. The resin is then transported to the extraction column by activation of the automatic valve at the base of the adsorption column discharging the resin into the transport line.

Figure 5 (7)

Details of Adsorption Column



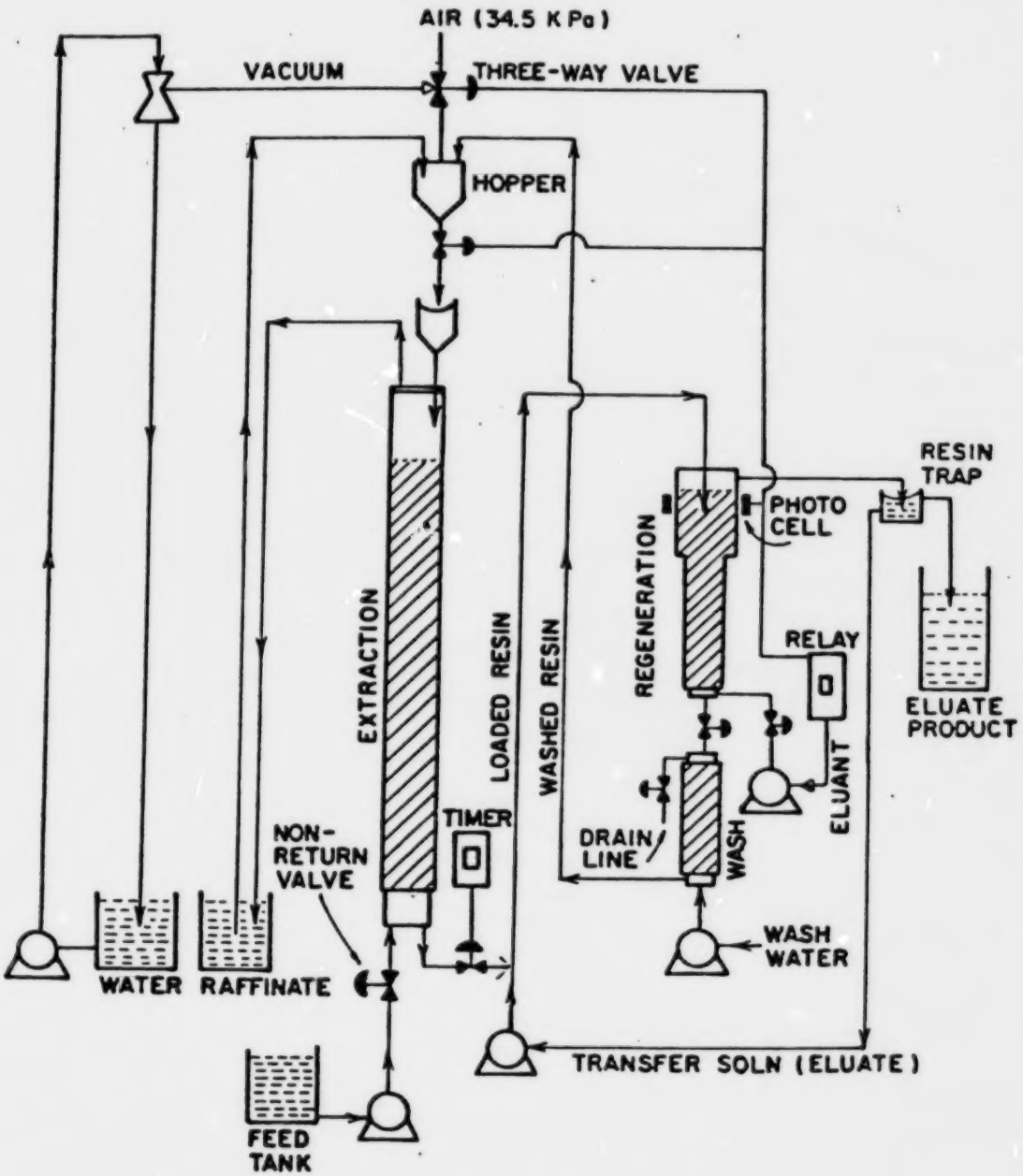

Feed Hopper

Adsorption Column

1. Liquid feed inlet
2. Non-return 12.7 mm (1/2 in.) valve
3. Timer
4. Lucite or polyethylene section
5. 50.8 mm (2 in.) and 152.4 mm (6 in.) coupling
6. 50.8 mm (2 in.) x 2.44 m (96 in.) pipe
7. Raffinate outlet
8. Plastic receiver (funnel)
9. Transfer solution inlet
10. Loaded resin outlet
11. 12.7 mm (1/2 in.) automatic ball valve
12. Washed resin inlet
13. Hopper discharge line
14. Washed resin inlet
15. Hopper 152.4 mm (6 in.) x 50.8 mm (2 in.) reducer
16. Rinse water
17. Vacuum line
18. 3-way solenoid valve
19. Compressed air 34.5 KPa (5 psig)
20. 12.7 mm (1/2 in.) automatic ball valve
21. 50.8 mm (2 in.) and 152.4 mm (6 in.) coupling

FIGURE 6 (7)

General Layout of Column Assembly



## 5.2 Testing of Ion-Exchange Column Assembly

The column assembly was water tested to insure that no leaks occurred. The system was then tested with Calgon GRC 22 activated carbon at 14x35 mesh and resins Duolite A-7 and Amberlite IRA 400. It was found that the automatic valves employed in the feed discharge hopper and at the bottom of the adsorption column, to discharge the loaded resin or carbon for transfer to the desorption column would not close properly when using carbon or Duolite A-7. This may be due to the hardness of the materials. The not-quite-tight closing of the feedhopper valve prevents the establishment of a vacuum required to transport of washed resin or carbon. It allows loaded eluant to enter the adsorption column. The multi-shaped form of those materials, together with their tendency to settle fast and tightly, also results in solution being drawn from the material, rather than transport it. Amberlite IRA 400 did not prevent closure of the valves and was transported without problems.

## 5.3 Test Materials

Based on benchscale testing, two ion exchange resins, Amberlite IRA 400 and Duolite A-7 and two activated carbons, Norit R 2515 and Calgon GRC 22, were selected for the column testing.

Amberlite IRA 400 is a "fisheye" type resin, 400 - 600 micron diameter.

Duolite A-7 consists of oddshaped particles and agglomerates with a size range from less than 400 to more than 800 microns.

Norit R 2515 is an extruded peatmoss based activated carbon, 5 mm long by 1 mm diameter.

Calgon GRC 22 as received was 16 x 6 mesh (1 x 3 mm).

During expansion testing it became apparent that the carbons in their original size could not be used in the ion exchange system, mainly because of transfer problems.

Calgon GRC 22 was ground and screened to 35 x 14 mesh and used at that size.

Norit R 2515 could only be size reduced through abrasion and was omitted from the program. Haycarb YAO at 35 x 14 mesh was substituted.

Gold solutions used in the testprogram were:

1) Synthetic gold solution made up from tapwater with gold added as KAuCN taken to pH 10.5 with $Ca(OH)_2$.

2) Campbell Red Lake Mines pregnant solution. The solution contained 10 ppm Au. Other constituents of the solution are listed in Table XII "Multi-Element Analysis of Campbell Pregnant Solution".

TABLE XII

CAMPBELL RED LAKE PREGNANT SOLUTION
(Composite from five (5) barrels)
March 3, 1987

| Element | Concentration mg/L |
|---|---|
| Co | 2.0 |
| Zn | 32 |
| Cd | < 0.02 |
| B | 0.54 |
| Bi | < 0.2 |
| P | < 0.5 |
| Be | < 0.002 |
| Si | 3.6 |
| Fe | 25 |
| Mn | 0.01 |
| Ca | 9.6 |
| Mg | 0.28 |
| Cu | 76 |
| Al | 0.84 |
| V | < 0.01 |
| Mo | 0.14 |
| Pb | < 0.02 |
| Ni | 41 |
| Cr | < 0.01 |
| Na | 915 |
| Au | 10 |
| NaCN | 1000 |

## 5.4 Expansion Testing

Expansion tests were conducted on the resins and carbons selected for the test program. The testing was in a 1.2 m high glass tube with a 5 cm inside diameter. The tube was of the same type as those in the ion exchange column assembly. The tests were with tap water, pumped by peristaltic pumps.

The tests were conducted to determine the voidage obtained at various flows.

Voidage is obtained from the heights of the expanded bed by applying the formula:

$$\frac{1-e}{0.63} = \frac{h_1}{h}$$

where: $e$ = Voidage

$h_1$ = Settled adsorbant height in meters

$h$ = Expanded adsorband height in meters

The results of expansion testing are shown in Tables XIII to XVII.

TABLE XIII
RESULTS OF EXPANSION TESTING

Material: Carbon Calgon GRC 22 (14x35 mesh)

| FLOW L/min | EXPANSION % | VOIDAGE |
|---|---|---|
| 0.60 | 34.0 | 0.53 |
| 0.65 | 44.0 | 0.56 |
| 0.75 | 54.0 | 0.59 |
| 0.85 | 62.0 | 0.61 |
| 0.90 | 64.0 | 0.62 |
| 1.0 | 76.0 | 0.64 |
| 1.10 | 87.0 | 0.66 |
| 1.15 | 97.0 | 0.68 |

TABLE XIV
RESULTS OF EXPANSION TESTING

Material: Carbon, Haycarb YAO (6x16 mesh)

| FLOW L/min | EXPANSION % | VOIDAGE |
|---|---|---|
| 0.85 | 7.5 | 0.41 |
| 1.0 | 15.1 | 0.45 |
| 1.5 | 23.0 | 0.51 |
| 2.0 | 41.5 | 0.55 |

TABLE XV
Material: Carbon Haycarb YAO (14x35 mesh)

| FLOW L/min | EXPANSION % | VOIDAGE |
|---|---|---|
| 0.56 | 44.2 | 0.56 |
| 0.68 | 61.5 | 0.61 |
| 0.88 | 78.8 | 0.65 |
| 1.04 | 98.1 | 0.68 |

TABLE XVI

RESULTS OF EXPANSION TESTING

Material: Resin Duolite A-7

| FLOW L/min | EXPANSION % | VOIDAGE |
|---|---|---|
| 0.2 | 24.0 | 0.49 |
| 0.33 | 52.0 | 0.59 |
| 0.44 | 88.0 | 0.64 |
| 0.63 | 140.0 | 0.78 |

TABLE XVII
RESULTS OF EXPANSION TESTING

Material: Resin Amberlite IRA 400

| FLOW L/min | EXPANSION % | VOIDAGE |
|---|---|---|
| 0.15 | 43.7 | 0.56 |
| 0.23 | 65.0 | 0.62 |
| 0.28 | 86.4 | 0.66 |
| 0.35 | 116.5 | 0.71 |

## 5.5 Static Loading Tests

To establish loading capacities and flowrates to obtain a chosen effluent quality and determine resin movement in the single stage column, a series of loading tests without resin transfer were conducted.

The results of loading tests with synthetic solution are shown in Tables XVIII to XXIII.

Results of loading from Campbell Red Lake Mines pregnant solution are shown in Tables XXIV to XXVI.

TABLE XVIII

BREAKTHROUGH TESTING

Material: Resin Duolite A-7, Vol. 0.80 L
Testfeed: Synthetic Solution, 3 ppm Au, pH 9.5
Flowrate: 0.2 L/min, Expansion 33.3%, Voidage 0.53

| Time/Hrs | Feed L | Au Recovery from Stream % | Au in Resin g/L |
|---|---|---|---|
| 1 | 12 | 100.0 | 0.046 |
| 2 | 24 | 99.3 | 0.099 |
| 3 | 36 | 91.8 | 0.141 |
| 4 | 48 | 77.0 | 0.176 |
| 5 | 60 | 66.9 | 0.209 |
| 6 | 72 | 60.3 | 0.235 |
| 7 | 84 | 50.8 | 0.259 |
| 8 | 96 | 52.8 | 0.282 |
| | Test interrupted - 16 hours | | |
| 9 | 108 | 70.2 | 0.315 |
| 10 | 120 | 62.0 | 0.344 |
| 11 | 132 | 54.1 | 0.369 |
| 12 | 144 | 50.5 | 0.391 |
| 13 | 156 | 42.6 | 0.411 |
| 14 | 168 | 40.0 | 0.430 |
| 15 | 180 | 44.6 | 0.450 |

TABLE XXIV

BREAKTHROUGH TEST

Material: Resin, Amberlite IRA 400, $H_2SO_4$ Conditioned. Vol. 0.4 L

Testfeed: Campbell Red Lake Mines, Pregnant Solution, 10 ppm Au, pH 11.1

Flowrate: 0.6 L/min., Expansion 142%, Voidage 0.74

| Time hours | Feed L | Au | | Cu | | Ni | | Zn | | Fe | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Recovery % | In Resin g/L | Recovery % | In Resin g/L | Recovery % | In Resin g/L | Recovery % | In Resin g/L | Recovery % | In Resin g/L |
| 1 | 36 | 72.0 | 0.648 | 68.4 | 4.678 | 86.8 | 3.202 | 82.8 | 2.385 | 28.0 | 0.630 |
| 2 | 72 | 32.9 | 0.936 | 19.7 | 6.026 | 48.8 | 5.002 | 43.8 | 3.648 | -- | -- |
| 3 | 108 | 17.5 | 1.120 | -- | -- | 34.1 | 6.260 | 31.2 | 4.546 | -- | -- |
| 4 | 144 | 8.5 | 1.198 | -- | -- | 22.0 | 7.072 | 18.8 | 5.088 | -- | -- |
| 5 | 180 | 1.0 | 1.208 | -- | -- | 14.6 | 7.610 | 12.5 | 5.448 | -- | -- |
| 6 | 216 | -- | -- | -- | -- | 7.3 | 7.880 | 9.4 | 5.718 | -- | -- |
| 7 | 252 | -- | -- | -- | -- | 14.6 | 8.418 | 12.5 | 6.078 | -- | -- |
| 8 | 288 | -- | -- | -- | -- | 12.2 | 8.688 | 6.2 | 6.256 | -- | -- |

TABLE XXV

BREAKTHROUGH TEST

**Material:** Resin, Amberlite IRA 400, Vol. 0.4 L

**Testfeed:** Campbell Red Lake Mines, Pregnant Solution, 10 ppm Au, pH 11.1

**Flowrate:** 0.57 L/min. Expansion 231%, Voidage 0.81

| Time hours | Feed L | Au | | Cu | | Ni | | Zn | | Fe | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Recovery % | In Resin g/L | Recovery % | In Resin g/L | Recovery % | In Resin g/L | Recovery % | In Resin g/L | Recovery % | In Resin g/L |
| 1 | 34 | 99.0 | 0.846 | 98.3 | 6.375 | 99.1 | 3.445 | 67.5 | 1.848 | 94.4 | 2.108 |
| 2 | 68.4 | 62.9 | 1.384 | 52.6 | 9.792 | 82.9 | 6.350 | 43.8 | 3.046 | 8.0 | 2.278 |
| 3 | 102.6 | 36.0 | 1.692 | 26.3 | 11.502 | 58.5 | 8.400 | 18.8 | 3.561 | -- | -- |
| 4 | 136.8 | 23.0 | 1.889 | 15.8 | 12.530 | 43.9 | 9.940 | 3.1 | 3.646 | -- | -- |
| 5 | 171.0 | 10.0 | 1.974 | 7.9 | 13.042 | 29.3 | 10.968 | -- | -- | -- | -- |
| 6 | 205.2 | 6.0 | 2.025 | 6.6 | 13.472 | 22.0 | 11.738 | -- | -- | -- | -- |

TABLE XXVI

BREAKTHROUGH TEST

Material: Carbon, Calgon GRC 22 (14x35 mesh), Vol. 0.6 L

Testfeed: Campbell Red Lake Mines, Pregnant Solution, 10 ppm Au, pH 11.1

Flowrate: 0.8 L/min. Expansion 54.2%, Voidage 0.59

| Time hours | Feed L | Au | | Cu | | Ni | | Zn | | Fe | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Recovery % | In Carbon g/L | Recovery % | In Carbon g/L | Recovery % | In Carbon g/L | Recovery % | In Carbon g/L | Recovery % | In Carbon g/L |
| 0.5 | 24 | 99.1 | 0.397 | 85.8 | 2.265 | 93.5 | 1.272 | 92.5 | 1.184 | 63.2 | 0.632 |
| 1.0 | 48 | 99.1 | 0.793 | 56.1 | 3.747 | 77.3 | 2.323 | 75.3 | 2.208 | 26.0 | 0.892 |
| 1.5 | 72 | 97.8 | 1.185 | 42.4 | 4.867 | 67.6 | 3.242 | 62.5 | 3.008 | 8.0 | 0.972 |
| 2.5 | 120 | 96.2 | 1.955 | 33.3 | 6.625 | 61.8 | 4.923 | 59.4 | 4.529 | 4.0 | 1.052 |
| 3.5 | 168 | 94.2 | 2.708 | 27.3 | 8.066 | 55.9 | 6.443 | 53.1 | 5.888 | -- | -- |
| 4.5 | 216 | 91.9 | 3.443 | 18.2 | 9.027 | 47.1 | 7.724 | 46.9 | 7.089 | -- | -- |
| 5.0 | 240 | 90.8 | 3.807 | 19.7 | 9.547 | 44.1 | 8.324 | 43.8 | 7.650 | -- | -- |
| 6.0 | 288 | 91.5 | 4.538 | 18.2 | 10.508 | 41.2 | 9.445 | 37.5 | 8.610 | -- | -- |
| 7.0 | 336 | 87.8 | 5.240 | 16.7 | 11.390 | 35.3 | 10.405 | 37.5 | 9.570 | -- | -- |
| 8.0 | 384 | 78.7 | 5.870 | 9.1 | 11.870 | 32.4 | 11.286 | 31.2 | 10.369 | -- | -- |
| 9.0 | 432 | 77.8 | 6.492 | -- | -- | 2.1 | 11.343 | 25.0 | 11.005 | -- | -- |
| 9.5 | 456 | 69.9 | 6.772 | -- | -- | 2.1 | 11.370 | 12.5 | 11.165 | -- | -- |

FIGURE 7

Breakthrough Curves

Duolite A-7

Synthetic Solution 3 ppm Au

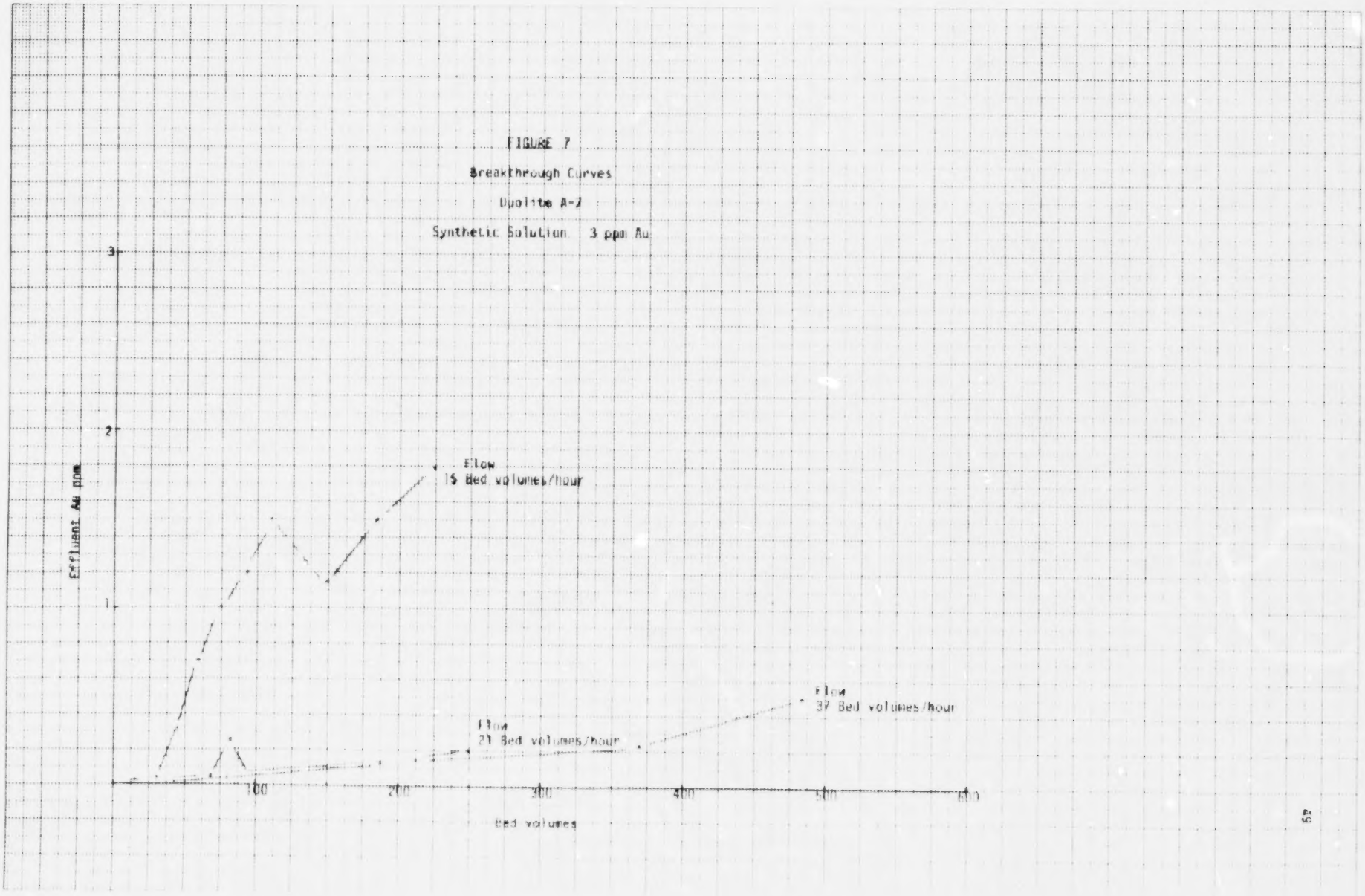


FIGURE 8

Breakthrough Curve

CALGON GRC 22

Synthetic Solution 6 ppm Au

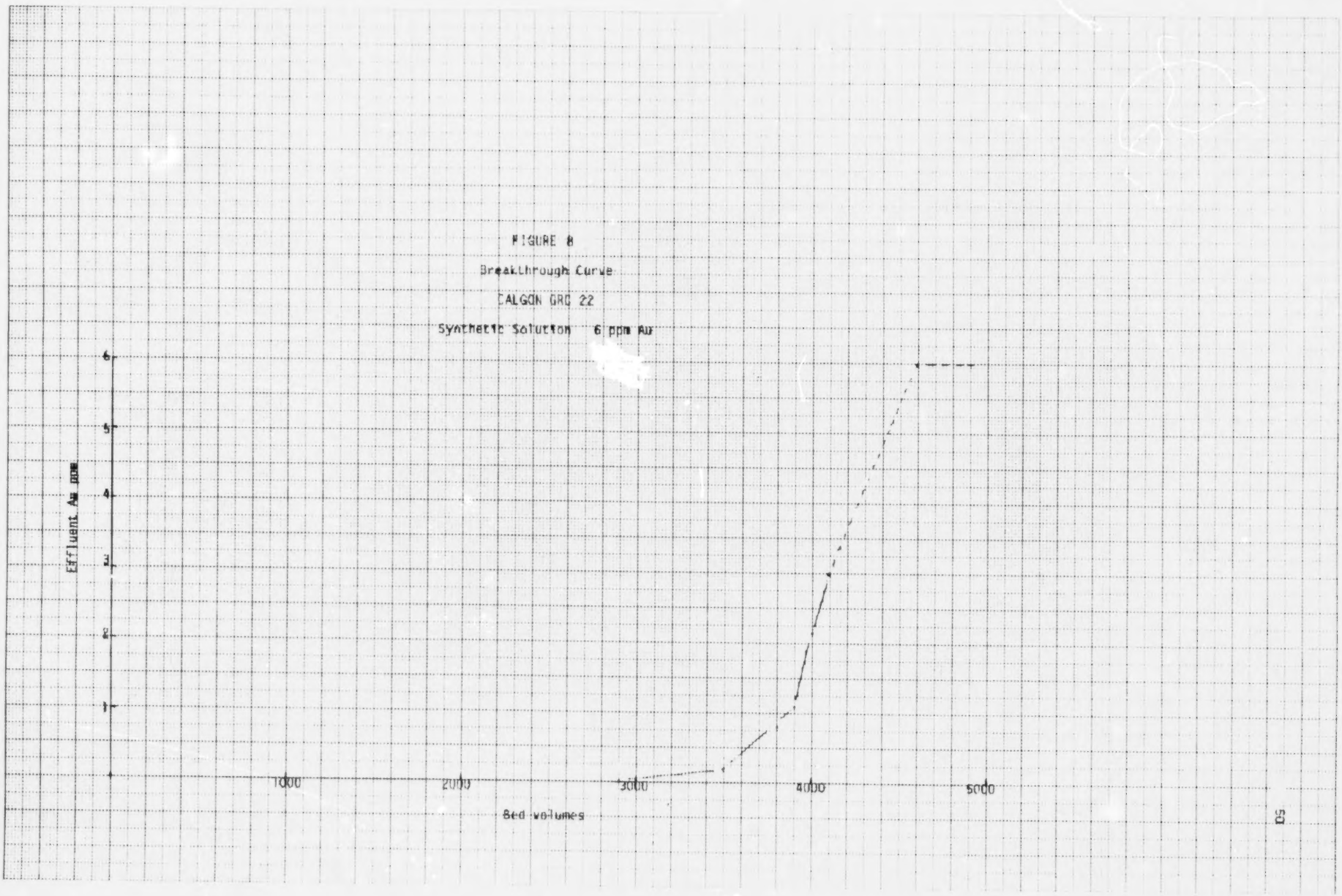


FIGURE 9

Breakthrough Curves

Haycarb HAU

Synthetic Solution 6 ppm Au

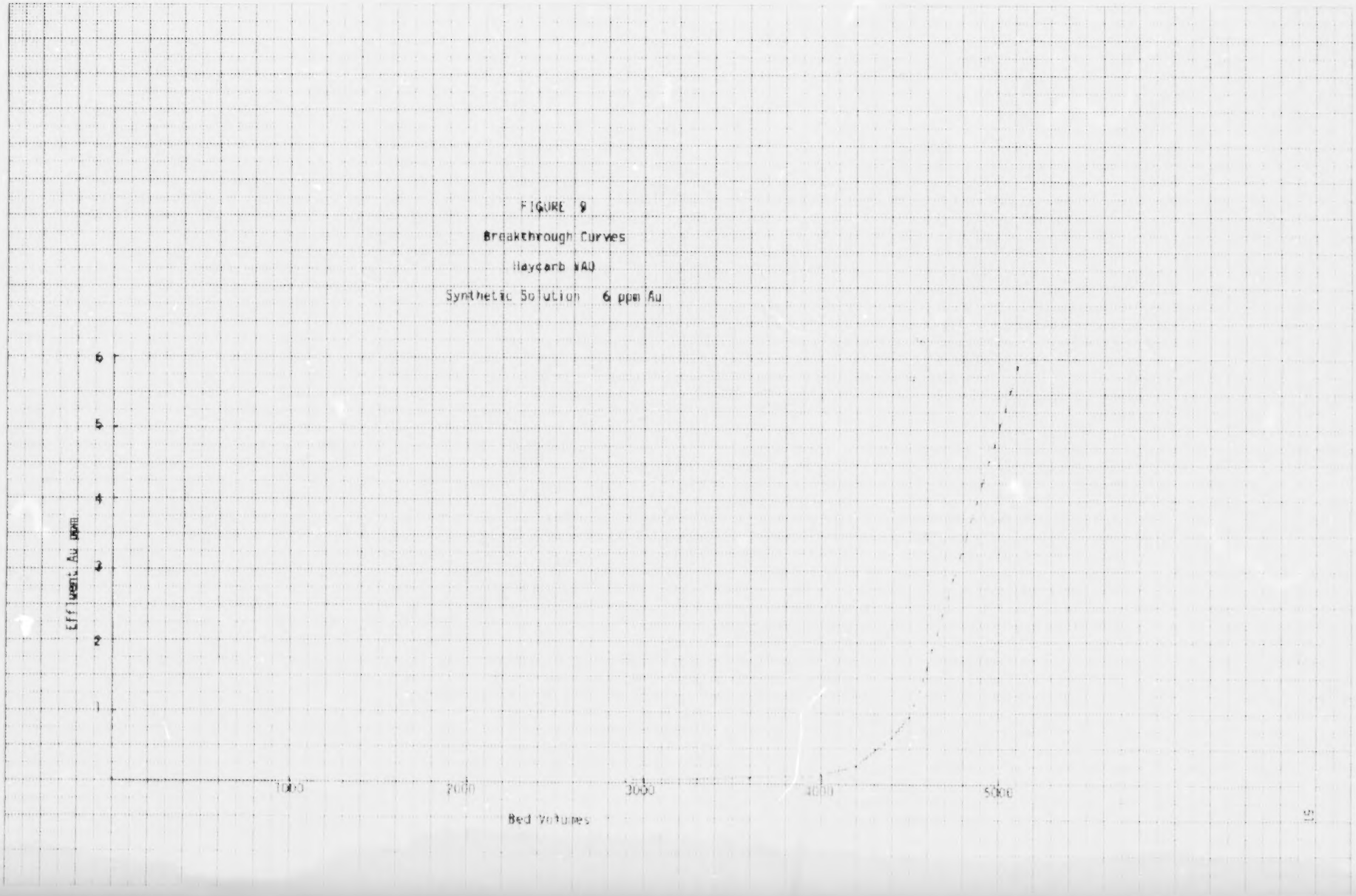


FIGURE 10

Breakthrough Curves

Amberlite IRA 400 - Calgon GRC 22

Campbell Preg. Solution 10 ppm Au

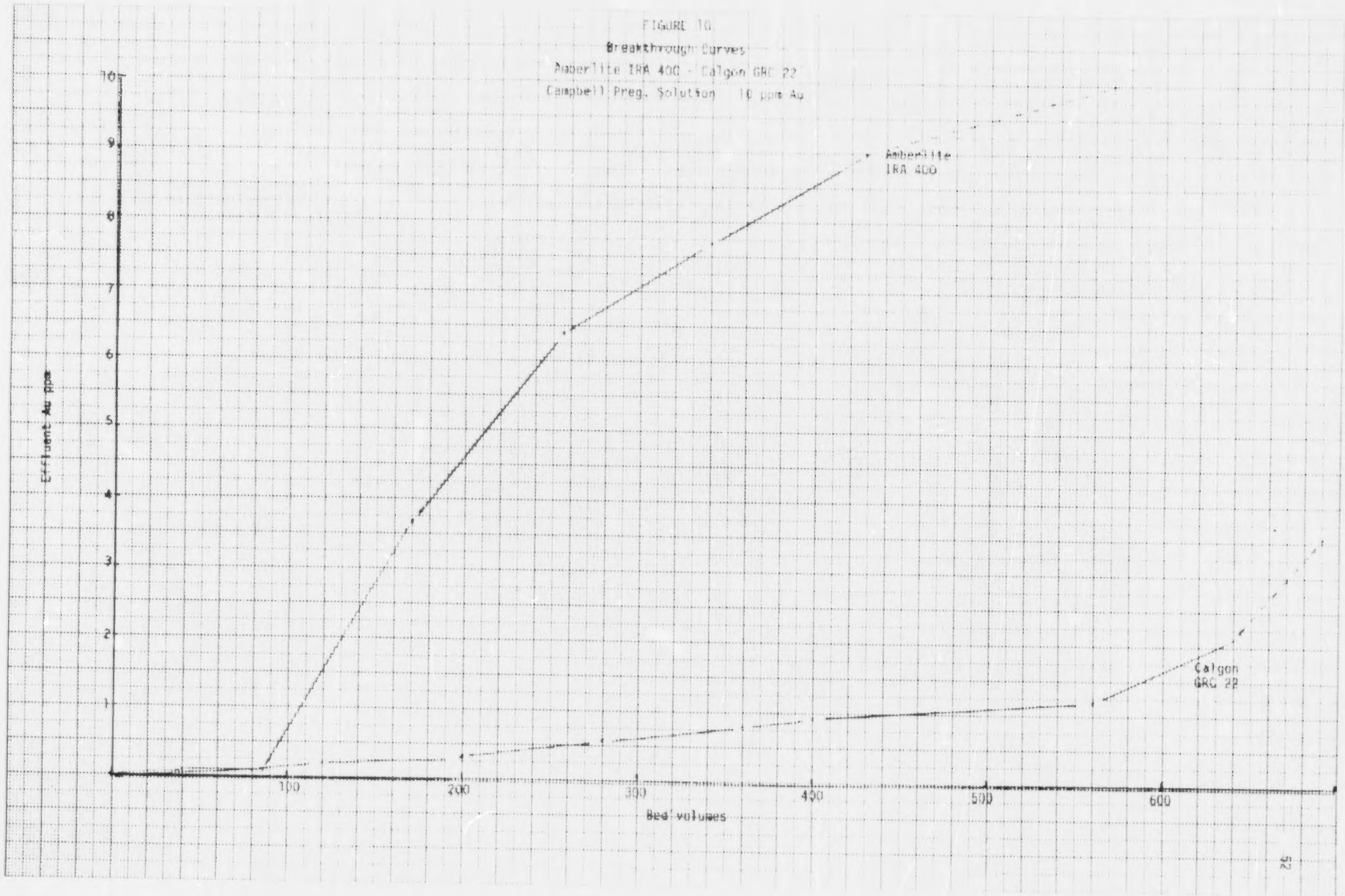


TABLE XIX

BREAKTHROUGH TESTING

Material: Resin Duolite A-7, Vol. 0.85 L
Testfeed: Synthetic Solution, 3 ppm Au, pH 9.5
Flowrate: 0.3 L/min, Expansion 89.5%, Voidage 0.67

| Time/Hrs | Feed L | Au Recovery from Stream % | Au in Resin g/L |
|---|---|---|---|
| 1 | 18 | 100.0 | 0.067 |
| 2 | 36 | 98.4 | 0.133 |
| 3 | 54 | 96.7 | 0.198 |
| 4 | 72 | 91.9 | 0.259 |
| 5 | 90 | 86.3 | 0.316 |
| 6 | 108 | 78.8 | 0.369 |
| 7 | 126 | 74.3 | 0.419 |
| | Test interrupted - 16 hours | | |
| 8 | 144 | 96.2 | 0.459 |
| 9 | 162 | 96.6 | 0.522 |
| 10 | 180 | 94.8 | 0.584 |
| 11 | 198 | 94.5 | 0.646 |
| 12 | 216 | 93.4 | 0.707 |

TABLE XX

BREAKTHROUGH TESTING

Material: Resin Duolite A-7, Vol. 0.650 L
Testfeed: Synthetic Solution, 3 ppm Au, pH 9.5
Flowrate: 0.4 L/min, Expansion 116%, Voidage 0.71

| Time/Hrs | Feed L | Au Recovery from Stream % | Au in Resin g/L |
|---|---|---|---|
| 1 | 24 | 100.0 | 0.108 |
| 2 | 48 | 98.6 | 0.214 |
| 3 | 72 | 98.3 | 0.319 |
| 4 | 96 | 96.9 | 0.423 |
| 5 | 120 | 95.5 | 0.525 |
| 6 | 144 | 93.8 | 0.625 |
| 7 | 168 | 91.7 | 0.725 |
| 8 | 192 | 90.0 | 0.819 |
| | Test interrupted - 16 hours | | |
| 9 | 216 | 94.1 | 0.920 |
| 10 | 240 | 92.4 | 1.019 |
| 11 | 264 | 90.3 | 1.116 |
| 12 | 288 | 87.9 | 1.210 |
| 13 | 312 | 84.1 | 1.300 |

TABLE XXI

BREAKTHROUGH TESTING

Material: Resin Amberlite IRA 400, Vol. 0.5 L

Testfeed: Synthetic Solution, 10 ppm Au, pH 9.5-10.0

Flowrate: 0.25 L/min (96 hours), Expansion 66%, Voidage 0.62
0.72 L/min (96-140 hours), Expansion 200%, Voidage 0.79

| Time/Hrs | Feed L | Au Recovery from Stream % | Au in Resin g/L |
|---|---|---|---|
| 4 | 60 | 100.0 | 1.2 |
| 24 | 360 | 100.0 | 7.2 |
| 48 | 720 | 100.0 | 14.4 |
| 72 | 1080 | 100.0 | 21.6 |
| 96 | 1440 | 100.0 | 28.8 |
| 100 | 1813 | 100.0 | 36.26 |
| 104 | 1990 | 100.0 | 39.8 |
| 108 | 2163 | 100.0 | 43.26 |
| 112 | 2336 | 100.0 | 46.72 |
| 116 | 2509 | 99.5 | 50.16 |
| 118 | 2595 | 99.6 | 51.88 |
| 120 | 2681 | 99.6 | 53.60 |
| 122 | 2767 | 99.5 | 55.32 |
| 124 | 2853 | 99.6 | 57.04 |
| 126 | 2939 | 99.0 | 58.75 |
| 128 | 3025 | 99.2 | 60.46 |
| 129 | 3068 | 98.5 | 60.88 |
| 130 | 3111 | 98.2 | 61.73 |
| 131 | 3154 | 98.2 | 62.58 |
| 132 | 3197 | 97.9 | 63.43 |
| 133 | 3240 | 98.3 | 64.28 |
| 134 | 3283 | 97.9 | 65.13 |
| 135 | 3326 | 97.6 | 65.97 |
| 136 | 3369 | 98.6 | 66.82 |
| 137 | 3412 | 98.6 | 67.25 |
| 138 | 3455 | 98.4 | 68.10 |
| 139 | 3498 | 98.5 | 68.95 |

TABLE XXII

BREAKTHROUGH TESTING

Material: Carbon, Calgon GRC 22 (14 x 35 mesh), Vol. 1.0 L
Testfeed: Synthetic Solution, 5 - 6 ppm Au, pH 9.5
Flowrate: 0.9 L/min, Expansion 72%, Voidage 0.64

| Time/Hrs | Feed L | Au Recovery from Stream % | Au in Resin g/L |
|---|---|---|---|
| 1 | 54 | 100.0 | 0.297 |
| 54 | 2916 | 100.0 | 16.04 |
| 56 | 3024 | 98.7 | 16.62 |
| 57 | 3078 | 98.5 | 16.91 |
| 58 | 3132 | 98.4 | 17.20 |
| 59 | 3186 | 98.5 | 17.49 |
| 60 | 3240 | 98.5 | 17.78 |
| 61 | 3294 | 98.4 | 18.07 |
| 62 | 3348 | 97.5 | 18.36 |
| 63 | 3402 | 96.9 | 18.65 |
| 64 | 3456 | 97.6 | 18.94 |
| 65 | 3510 | 96.9 | 19.23 |
| 66 | 3564 | 96.2 | 19.52 |
| 67 | 3618 | 95.5 | 19.80 |
| 68 | 3672 | 93.5 | 20.08 |
| 69 | 3726 | 91.3 | 20.35 |
| 70 | 3780 | 88.2 | 20.61 |
| 71 | 3834 | 86.4 | 20.87 |
| 72 | 3888 | 81.8 | 21.11 |
| 73 | 3942 | 69.6 | 21.32 |
| 74 | 3996 | 64.2 | 21.51 |
| 75 | 4050 | 50.4 | 21.66 |

TABLE XXIII

BREAKTHROUGH TESTING

Material: Carbon, Haycarb YAO (14 x 35 mesh), Vol. 1.0 L
Testfeed: Synthetic Solution, 6 ppm Au, pH 9.5
Flowrate: 1.0 L/min, Expansion 69.2%, Voidage 0.62

| Time/Hrs | Feed L | Au Recovery from Stream % | Au in Resin g/L |
|---|---|---|---|
| 4 | 240 | 100.0 | 1.44 |
| 48 | 2880 | 100.0 | 17.28 |
| 50 | 3000 | 99.4 | 18.00 |
| 52 | 3120 | 99.2 | 18.66 |
| 53 | 3180 | 99.0 | 19.02 |
| 54 | 3240 | 99.0 | 19.38 |
| 55 | 3300 | 99.2 | 19.74 |
| 56 | 3360 | 98.8 | 20.10 |
| 57 | 3320 | 98.7 | 20.46 |
| 58 | 3480 | 98.5 | 20.81 |
| 59 | 3520 | 98.7 | 21.17 |
| 60 | 3600 | 98.7 | 21.52 |
| 61 | 3660 | 98.5 | 21.87 |
| 62 | 3720 | 97.7 | 22.22 |
| 63 | 3780 | 97.2 | 22.57 |
| 64 | 3840 | 97.3 | 22.92 |
| 65 | 3900 | 97.2 | 23.27 |
| 66 | 3960 | 96.5 | 23.62 |
| 67 | 4020 | 95.8 | 23.96 |
| 68 | 4080 | 94.0 | 24.30 |
| 69 | 4140 | 92.0 | 24.63 |
| 70 | 4200 | 90.2 | 24.95 |
| 71 | 4260 | 88.3 | 25.25 |
| 72 | 4320 | 84.0 | 25.55 |
| 73 | 4380 | 80.7 | 25.84 |
| 74 | 4440 | 74.2 | 26.11 |

The Breakthrough curves are illustrated in Figures 7 to 9.

The breakthrough curve for the testing of Amberlite IRA 400 with synthetic solution is not illustrated as 98% of the gold was still absorbed after 7082 bed volumes of solution were passed through the resin.

The adsorption of gold from Campbell Red Lake Mines pregnant solution in both Amberlite IRA 400 and CALGON GRC 22 is illustrated in Figure 10.

It is shown, that with other metals present, the capacity for gold adsorption is lowered in both resin and carbon, but much more pronounced in IRA 400.

## 5.6 Elution Testing

Elution testing was conducted on Amberlite IRA-400 loaded from synthetic solution and Campbell Red Lake Mines pregnant solution. It was also conducted on CALGON GRC 22 loaded from synthetic solution.

Stripping of the metals from IRA 400 was by electro-elution and the novel procedure of KSCN stripping. Stripping of the carbon was by electro-elution only.

## 5.7 KSCN Elution

A novel procedure for stripping gold from resin was applied in the current program. It involves stripping with 4.88 KSCN (potassium thiocyanate in a 50 % (volume) $H_2O$, 50 % (volume) dimethyl formamide solution. The advantage of the method is, that the stripped gold combines with KCN in the solution and crystallizes out of the solution as KAuCN, a marketable product.

Two tests were conducted with synthetic solution loaded IRA 400. The tests were at 50°C, in a heated glass column. The stripping solution was heated before pumping to the top of the resin charge. 1.2 and 1.1 liters of stripping solution were used. Test R-1 was at a flowrate of 20 mL/min, Test R-2 was at 6 mL/min. In both tests the stripping was incomplete with gold recoveries of 76.8 and 67.5 % respectively. The recovery calculations were based on solution analysis. No resin analysis were performed.

In a third test (R-3) the same eluant was used to strip two batches of IRA 400 loaded from Campbell pregnant solution. Stripping and washing removed 88 % of the gold from the first resin and 69% of the gold from the second resin. More than 50 % of the copper was not stripped from the first resin and 23 % of the copper remained in the second resin. Ni and Zn were better than 90 % stripped but iron was not stripped very well by the eluant. More of the iron was removed in the washing.

The results are listed in Tables XXVII to XXIX.

TABLE XXVII

Elution Test R-1

Material: Make up Solution Loaded Resin, Amberlite IRA 400,
Vol. 0.15 L Au = 9 g

Eluant: 4.88 Molar KSCN in 50% Vol. dist. $H_2O$ -
50% Vol. Dimethylformamide

Flowrate: 0.020 L/min Temp. 50° C.

| TIME/MIN | VOL/L | Au g | Au g CUM. | Au STRIPPED % |
|---|---|---|---|---|
| 12 | 0.230 | 1.989 | 1.989 | 22.1 |
| 24 | 0.477 | 2.766 | 4.755 | 52.8 |
| 36 | 0.723 | 1.476 | 6.231 | 69.2 |
| 48 | 0.969 | 0.509 | 6.740 | 74.9 |
| 60 | 1.214 | 0.174 | 6.914 | 76.8 |

TABLE XXVIII

Elution Test R-2

Material: Make up Solution Loaded Resin, Amberlite IRA 400,
Vol. 0.15 L Au = 9 g

Eluant: 4.88 Molar KSCN in 50% Vol. dist. $H_2O$ -
50% Vol. Dimethylformamide

Flowrate: 0.006 L/min Temp. 50° C.

| TIME/MIN | VOL/L | Au g | Au g CUM. | Au STRIPPED % |
|---|---|---|---|---|
| 30 | 0.18 | 2.628 | 2.628 | 29.2 |
| 60 | 0.358 | 1.833 | 4.461 | 49.6 |
| 90 | 0.54 | 1.001 | 5.462 | 60.7 |
| 120 | 0.698 | 0.408 | 5.870 | 65.2 |
| 150 | 0.886 | 0.150 | 6.020 | 66.9 |
| 180 | 1.106 | 0.056 | 6.076 | 67.5 |

TABLE XXIX

ELUTION TEST R-3 MATERIALS BALANCE

Material: Campbell Loaded Resin, Amberlite IRA 400 Volume: First Resin 0.5 L, Second Resin 0.4 L.
Eluant : 4.88 M KSCN in 50% $H_2O$ and 50% Dimethylformamide.
Eluant from first strip used to strip loaded resin II.

| | | Au | | Cu | | Ni | | Zn | | Fe | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vol.L | g | Dist % | g | Dist % | g | Dist % | g | Dist % | g | Dist % |
| Loaded Resin | 0.5 | 0.964 | 100.0 | 6.743 | 100.0 | 5.869 | 100.0 | 1.823 | 100.0 | 1.094 | 100.0 |
| Eluant (KSCN) | 1.2 | 0.840 | 86.7 | 2.880 | 42.7 | 5.280 | 90.0 | 1.80 | 98.7 | 0.168 | 15.4 |
| Wash (Dist $H_2O$) | 0.5 | 0.012 | 1.3 | 0.037 | 0.5 | 0.070 | 1.2 | 0.016 | 0.9 | 0.455 | 41.6 |
| Stripped Resin | 0.5 | 0.112 | 12.0 | 3.826 | 56.8 | 0.519 | 8.8 | 0.007 | 0.4 | 0.471 | 43.0 |
| | | | | | | | | | | | |
| Loaded Resin II | 0.4 | 0.775 | 100.0 | 5.394 | 100.0 | 4,695 | 100.0 | 1.485 | 100.0 | 0.875 | 100.0 |
| Eluant (KSCN) | 1.2 | 0.423 | 55.7 | 3.840 | 71.2 | 3.840 | 81.8 | 1.80 | +100 | 0.190 | 21.7 |
| Wash (Dist $H_2O$) | 0.5 | 0.103 | 13.3 | 0.315 | 5.8 | 0.510 | 10.9 | 0.430 | - | 0.410 | 46.9 |
| Stripped Resin II | 0.4 | 0.240 | 31.0 | - | 23.0 | - | 7.3 | - | - | - | 31.4 |
| Eluant after stripping 2 resins | 1.2 | 1.272 | - | 6.720 | - | 9.120 | - | 3.60 | - | 0.358 | - |
| Comb. Wash Sol. | 1.0 | 0.115 | - | 0.352 | - | 0.580 | - | 0.456 | - | 0.865 | - |

## 5.8 Electro Elution

In electro elution, the resin or carbon is stripped in the same vessel where the gold is plated from the electrolyte onto a steel wool cathode by an electro motive force.

Tests were conducted in a 25.4 cm diameter, 35.6 cm stainless steel vessel which acts as the anode. Electroplating is on stainless steel wool wedged between 16.5 cm diameter perforated steel plates, fastened to the solution feed tube which is the cathode.

Distance between steel plates is 10 cm. For electro elution of loaded carbon, the vessel is equipped with a heating mantle and strip solution is pumped from an insulated heating tank. Testing was conducted on Calgon GRC 22 loaded from artificial solution and on Amberlite IRA 400, also loaded from artificial solution.

Stripping solution for carbon contained 1% NaOH and 0.1% NaCN. Stripping of resin was with 0.20% NaOH, 0.1% NaCN and 5 g/L Zn.

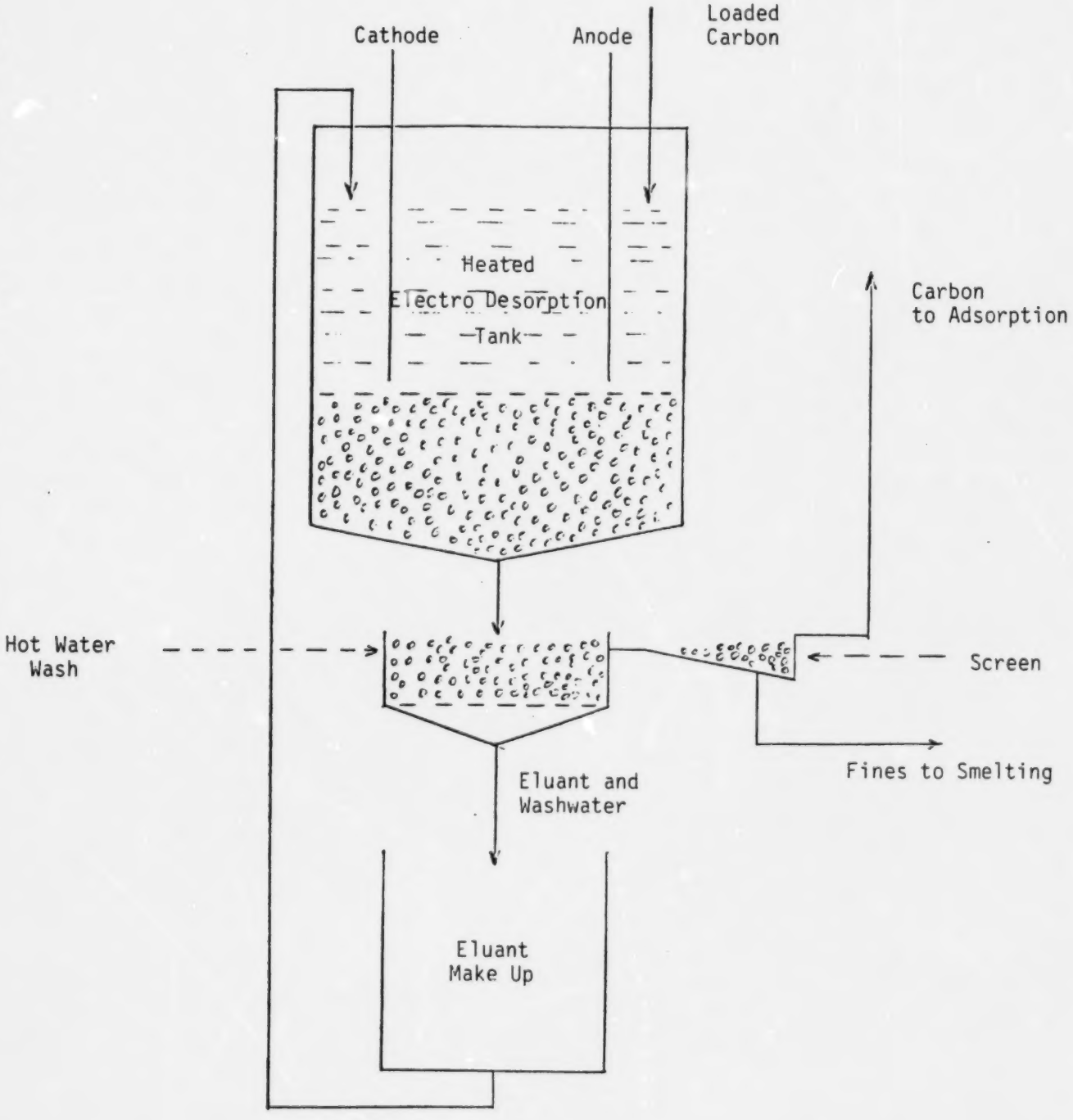
Carbon subjected electro elution was Calgon GRC 22, loaded from synthetic solution. Resin tested was Amberlite IRA 400 also loaded from synthetic solution.

The Calgon GRC 22 elution test was run with 0.4 litres of loaded carbon. Flowrate of eluant was 0.2 L/min. equal to 30 bed volumes per hour. Temperature was 85$^{o}$C. Gold was stripped at the rate of 120 ppm per litre (calculated). Electro depositing was at 3.0 Amp. The effluent contained from 1.2 to 1.8 ppm Au for a gold recovery of 98.5 to 99.0% on the steel wool.

The IRA 400 resin was electro eluted at room temperature. Other conditions were similar to the carbon test. Gold was stripped at the rate of 200 ppm per litre. Effluent gold content was 0.4 to 0.8 ppm for a gold recovery of more than 99%. A suggested flowsheet for electro elution is shown in Figure 11.

Figure 11

Suggested Flowsheet for Electro Elution



## 5.9 Continuous Testing

Amberlite IRA 400 was used in continuous testing. Due to heat requirement in elution with KSCN in diethylene formamide, only the adsorption part of the ion exchange column assembly could be utilized. Resin exchange was manual.

Loading was from Campbell Red Lake Mines pregnant solution, at a flowrate of 0.6 L/min. Two litres of resin were used. The testing showed that by exchanging 0.5 L of resin per hour, an effluent free of metals can be obtained. After 4 hours when the resin has been exchanged completely, the loading capacity is settled.

The loading pattern is illustrated in the metallurgical balances of repeat loading of IRA 400 from Campbell Red Lake Mines pregnant solutions, in Table XXX.

It is demonstrated that with loading from Campbell pregnant solution, IRA 400 will load to approximately 1 g Au, 6 g Cu, 4 g Ni, 1.5 - 2 g Zn and 1.5 - 2 Fe on a continuous basis.

Table XXX

METALLURGICAL BALANCE OF REPEAT RESIN LOADING

aterials: Resin Amberlite IRA 400, loaded with Campbell Red Lake Mines Pregnant Solution Stripped with KSCN - Dimethylformamide - $H_2O$ Solution.

| TIME Hrs | FEED L | Au Recovery from Str. % | Au In Resin g/L | Cu Recovery from Str. % | Cu In Resin g/L | Mo Recovery from Str. % | Mo In Resin g/L | Zn Recovery from Str. % | Zn In Resin g/L | Fe Recovery from Str. % | Fe In Resin g/L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (FIRST LOADING) | | | | | | | | | | | |
| 1 | 34.2 | 99.0 | 0.846 | 98.3 | 6.375 | 99.1 | 3.445 | 67.5 | 1.848 | 94.4 | 2.108 |
| 2 | 68.4 | 62.9 | 1.384 | 52.6 | 9.792 | 82.9 | 6.350 | 43.8 | 3.046 | 8.0 | 2.278 |
| 3 | 102.6 | 36.0 | 1.692 | 26.3 | 11.502 | 58.5 | 8.400 | 18.8 | 3.561 | - | 2.278 |
| 4 | 136.8 | 23.0 | 1.889 | 15.8 | 12.530 | 43.9 | 9.940 | 3.1 | 3.646 | - | 2.278 |
| 5 | 171.0 | 10.0 | 1.974 | 7.9 | 13.042 | 29.3 | 10.986 | - | 3.646 | - | 2.278 |
| 6 | 205.2 | 6.0 | 2.025 | 6.6 | 13.472 | 22.0 | 11.738 | - | 3.646 | - | 2.278 |
| (SECOND LOADING) | | | | | | | | | | | |
| In Resin | | | 0.4 | | 5.4 | | 1.2 | | - | | 0.9 |
| 1 | 36 | 87.2 | 1.185 | 52.0 | 8.910 | 84.9 | 4.333 | 59.4 | 1.555 | 56.0 | 2.160 |
| 2 | 72 | 38.0 | 1.527 | 25.3 | 10.618 | 70.7 | 6.942 | 34.4 | 2.546 | 8.0 | 2.273 |
| 3 | 108 | 10.3 | 1.620 | 2.7 | 10.800 | 22.0 | 7.794 | 31.2 | 3.444 | - | 2.273 |
| 4 | 144 | 9.1 | 1.702 | 5.3 | 11.158 | 24.4 | 8.644 | 25.0 | 4.164 | - | 2.273 |
| 5 | 180 | 8.5 | 1.784 | - | 11.158 | 17.1 | 9.275 | - | 4.164 | - | 2.273 |
| 6 | 216 | 7.9 | 1.849 | 2.7 | 11.340 | 19.5 | 9.995 | - | 4.164 | - | 2.273 |
| (THIRD LOADING) | | | | | | | | | | | |
| In Resin | | | 0.4 | | 4.5 | | 1.0 | | - | | 0.9 |
| 0.25 | 9 | 89.5 | 0.601 | 87.5 | 5.977 | 94.6 | 1.873 | 92.5 | 0.666 | 63.2 | 1.250 |
| 0.5 | 18 | 64.8 | 0.755 | 61.3 | 6.011 | 81.2 | 2.622 | 75.3 | 1.208 | 16.0 | 1.340 |
| 0.75 | 27 | 54.0 | 0.877 | 49.3 | 7.843 | 73.2 | 3.297 | 62.5 | 1.658 | 8.0 | 1.385 |
| 1 | 36 | 47.6 | 0.984 | 4.13 | 8.540 | 68.3 | 3.927 | 59.4 | 2.086 | 4.0 | 1.408 |
| 1.25 | 45 | 43.2 | 1.081 | 36.0 | 9.148 | 63.4 | 4.511 | 53.1 | 2.468 | - | 1.408 |
| 1.5 | 54 | 37.0 | 1.164 | 28.0 | 9.620 | 56.1 | 5.028 | 46.9 | 2.806 | - | 1.408 |
| 1.75 | 63 | 33.0 | 1.238 | 29.3 | 10.114 | 53.7 | 5.523 | 43.7 | 3.144 | - | 1.408 |
| 2 | 72 | 29.0 | 1.303 | 28.0 | 10.568 | 51.2 | 5.995 | 37.5 | 3.414 | - | 1.408 |

## 6.0 CONCEPTUAL FLOWSHEET AND ECONOMIC EVALUATION

Capital and operating costs of hypothetical operations employing conventional carbon adsorption and deep fluidized bed ion exchange adsorption have been estimated. Since operation of the fluidized bed on pulps was not demonstrated, substantially clear solutions from filters or heap leach operation are assumed. A heap leach flowsheet was selected for the comparison.

The pregnant liquor was assumed free of significant content of metals (cobalt, copper, nickel, zinc, iron) that compete with gold for loading sites on strong base resin (IRA-400). Many heap leach operations do, indeed, provide such clean solutions.

Costs of electro elution and potassium thiocyanate-dimethyl formamide elution were separately estimated.

Flowsheet data was drawn principally from test results, but supplemented where necessary by plausible assumptions or accepted plant practice.

### 6.1 Summary and Conclusions

Flowsheet and costs were developed for recovering gold from heap leach pregnant solution by the following alternatives:

Case A: conventional upflow carbon adsorption
atmospheric elution with caustic/cyanide
electrowinning not included

Case B: deep fluidized bed strong base resin adsorption
elution with sodium thiocyanate-dimethyl formamide
recovery of gold from eluate not included

Case C: deep fluidized bed strong base resin adsorption
electro elution wilh caustic/sodium cyanide/zinc
cyanide gold recovered on steel wool

The flowsheet for case B is illustrated in Figure 12.

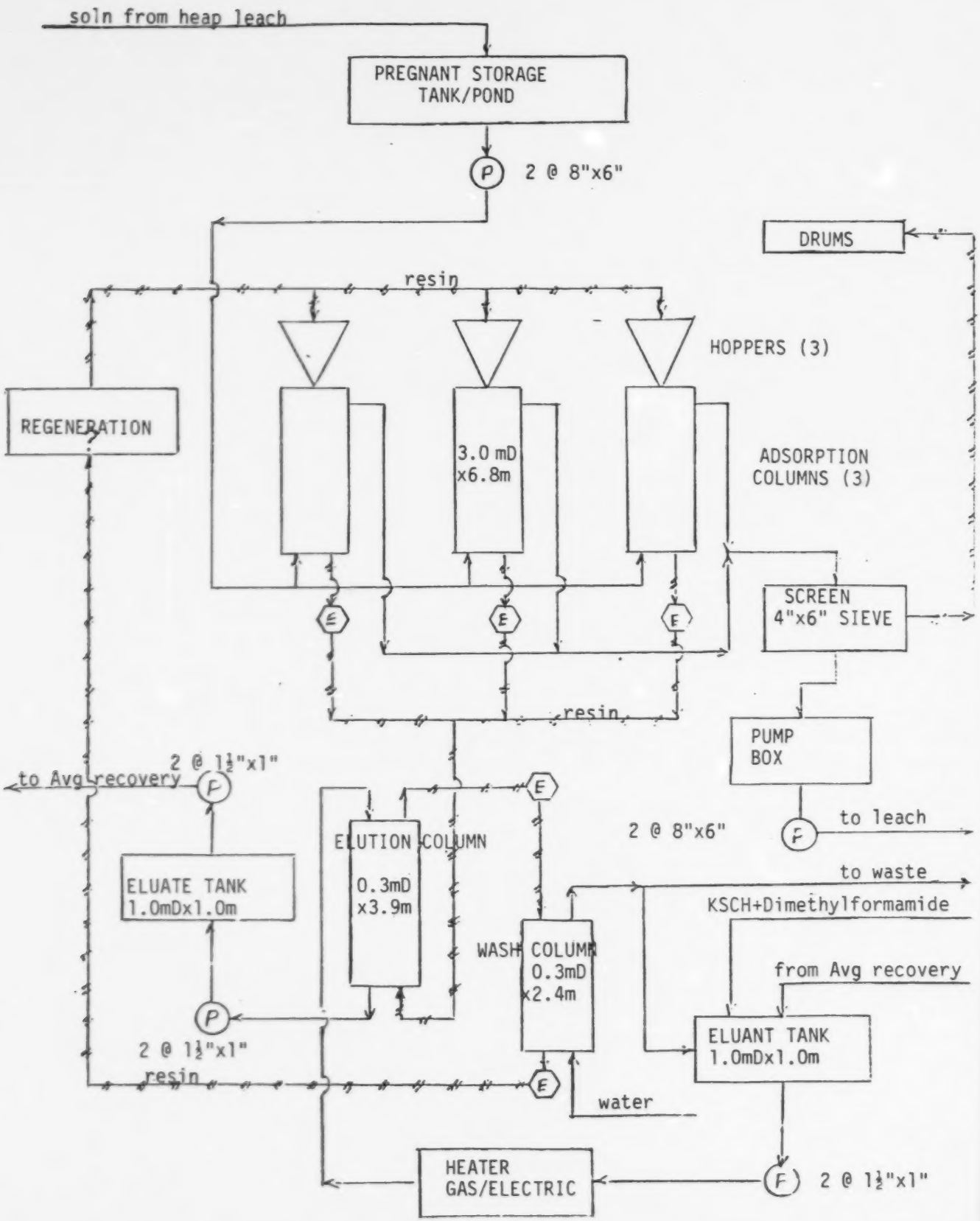
Capital costs were estimated as follows:

| | Case A | Case B | Case C |
|---|---|---|---|
| Plant Cost | $617,000 | $ 426,000 | $ 458,000 |
| Adsorbant Cost | $ 95,800 | $ 689,200 | $ 748,200 |
| Total capital cost | $712,800 | $1,115,200 | $1,206,200 |
| Operating cost, $/y | $337,000 | $ 475,000 | $ 380,000 |

Plant cost for the deep fluidized bed systems are 69 % and 74 % of the conventional case. However the cost of the strong base resin greatly exceeds that of carbon giving overall capital costs for the ion exchange systems of 156 and 169 % of conventional carbon adsorption.

FIGURE 12
CASE B: ION EXCHANGE WITH IRA 400
CLEAN SOLUTION, NaSCN + DMF ELUTION

FLOWSHEET



## GENERAL DESIGN CRITERIA

FEED SOLUTION

| | | |
|---|---|---|
| - Source | = | heap leach |
| - Volume | = | 4,000 lpm |
| - Gold assay | = | 3 ppm |
| - Solids content | = | 50 ppm |

Final Product = eluate

Operating Schedule

| | | |
|---|---|---|
| - hours per day | = | 24 |
| - days per year | = | 350 |

Equipment Availability = 93%

Impurities intent of feed solution to be set for each case.

Recovery of Gold by Single Stage Deep Fluidized Bed, Ion Exchange and Carbon Technique

## A. DESIGN CRITERIA

### Adsorption

| | |
|---|---|
| - number stages | = 5 |
| - height/diam. ratio of carbon column(at rest) | = calculate |
| - carbon expansion during loading | = 50% |
| - frequency carbon advance | = 24 hr intervals |
| - carbon intent each column (stage) | = 2 advances |
| - method carbon advance | = eductors |
| - leach solution flow rate | = 600 lpm |
| - temperature | = ambient |
| -impurities in leach solution | = low |
| - gold assay carbon - barren | = 40g/tonne (dry basis) |
| - loaded | = 8,000g/tonne(dry basis) |
| - gold recovery | = 97.5% |
| - bulk density dry carbon | = 400 kg/$m^3$ |

### Stripping

| | |
|---|---|
| - number stages | = 1 (2 vessels) |
| - barren strip solution comp.- NaOH | = 1.0% |
| - NaCN | = 0.1% |
| - time | = 48 hours |
| - temperature | = 95$^{o}$C |
| - pressure | < 100 kPa |
| - strip solution flow rate | = 72 lpm/tonne carbon |
| - strip vessel height/diam. ratio | = 3 |

### Carbon Regeneration

| | |
|---|---|
| - amount carbon regenerated | = 25% |
| - type equipment | = direct fired rotary kiln |
| - temperature | = 600$^{o}$C |

A. FLOW CALCULATIONS

LEACH SOLUTION

- volume - numerical = 4,000 lpm
- design = 4,000/.93 = 4,300 lpm
- weight - 4,300 x 1,440/1,000 = 6,192 tonnes/day

ADSORPTION GOLD

- daily wt. in leach soln. = 6,192 x 3 = 18,576 g
- daily wt. to carbon = 18,576 x .975 = 18,112 g

ADSORPTION CARBON

- daily wt. = 18,112 (8,000-40) = 2.28 tonnes(dry)
- wt. per advance = as daily wt. = 2.28 tonnes(dry)
- wt. per column = 2.28 x 2 = 4.56 tonnes(dry)
- vol. per advance = 2.28 x 1,000/400 = 5.70 $m^3$
- at rest vol. per column = 5.70 x 2 = 11.40 $m^3$

STRIP CARBON

- vol. per advance = as adsorption = 5.70 $m^3$
- vol. per column = as advance = 5.70 $m^3$
- wt. per column, dry unloaded basis = 2.28 tonnes

STRIP SOLUTION

- vol. = 2.28 x 7.2/.92 = 177 lpm
- wt. = 177 x 1 x 1.05/1,000 = 0.19 tonnes/min.

TRANSFER CARBON

- assume 40 min. transfer and volume 50% greater than at rest volume
- vol. = 5.70 x 1.5 x 1,000/40 = 214 lpm
- wt. solids = 2.28 x 1,000/40 = 57 kg/min

A. EQUIPMENT CALCULATIONS

PREGNANT SOLUTION POND

| | |
|---|---|
| Design capacity - time | = 24 hours |
| - volume = 4,000 x 1,440/1,000 | = 5,760 $m^3$ |

This will be a earthen pond lined with polyethylene, butyl rubber or some other impermeable membrane. It need not be cisted for the exercise as it is common to all cases.

ADSORPTION COLUMNS

| | |
|---|---|
| Design capacity - vol. carbon at rest | = 11.40 m3 |
| - vol. carbon expanded | = 17.10 $m^3$ |
| - leach solution flow | = 4,300 lpm |
| Area = 4,300/600 | = 7.17 $m^2$ |
| D = 7.17 x 4/ | = 3.02 m |
| H = 11.40/3.02 | = 3.78 m |
| Specs - diam | = 3.0 m |
| - height 3.8x1.5 +0.5+0.3 | = 6.5 m |
| - material | = carbon steel |
| - number | = 5 |

BARREN SOLUTION PUMP BOX

| | |
|---|---|
| Design capacity @ 1 min. = 4,000 x 1/1,000 | = 4 $m^3$ |
| D = 4 x 4/ = 1.72 | |
| Specs - diam. | = 1.80 m |
| - height | = 1.80 m |
| - material | = carbon steel |

BARREN STRIP TANK

Design capacity @ 4 hours = 177 x 60 x 4/1,000 = 42.5 $m^3$

D = 42.5 x 4/ = 3.78 m

Specs - diam. = 4.0 m
- height = 4.0 m
- material = carbon steel

Strip Columns

Design capacity

= 5.70 $m^3$

$D^2 x 3D/4 = 5.70$

D= 5.70x4/ x3=1.34 m

Specs: - diam. = 1.40 m
- height = 1.38 x 3 + 0.3 = 4.50 m
- materials = carbon steel
- number = 2

HEAT EXCHANGERS

Design capacity = 177 (95 - 80) = 2,650 Kcal/min

Specs: - number = 2
- type = shell & tube(for casting only)
- materials = carbon steel & teflon

ROTARY KILN

Design capacity

- dry carbon = 2.28 x .25 x 1,000 = 570 kg/day
- wet carbon @ 25% $H_2O$ = 570/.75 = 760 kg/day

Specs - type = direct fired rotary
- diameter = 24"
- length = 15'
- motor hp, incl. fan = 2
- fuel = natural gas

ROTARY KILN FEED BIN

Design capacity = 5.70 x .25 x 1.25 = 1.78 $m^3$

Specs - diameter = 1.2 m
- height = 2.4 m
- cone slope = $60^o$
- materials = carbon steel

ROTARY KILN FEEDER

Design capacity = 760 x 1.25/1,440 = 0.66 kg/min

Specs - type = screw
- diameter = 15 cm
- length = 3.0 m
- motor hp = 1/2

CARBON SCREEN

Design capacity - slurry = 214 lpm
- solids = 57 kg/min

Specs - type = Sweeco rotary
- diameter = 48"
- motor hp = 2 1/2

PUMPS

| | Adsorption Feed | Barren | Strip Feed |
|---|---|---|---|
| Design cap, USGPM | 4300x1.25/3.785=1400 | as ads feed=1400 | 177x1.25/3.785= 60 |
| Design head,feet $H_2O$ | = 60 | = 60 | 60 x 2 + 20 =140 |
| Specs - style | horiz. cent. | horiz. cent. | horiz. cent. |
| - size | 8" x 6" -13" | 8" x 6" - 12" | 1 1/2"x1"-7"(3500) |
| - number, w. space | 2 | 2 | 2 |
| - motor hp, Total | 10 x 2 = 20 | 7.5 x 2 = 15 | 5 x 2 = 10 |

ROTARY EDUCTOR KILN

Design cap. USGPM estimate = 40

Design head, feet, $H_2O$ = 50

Specs - style = horiz. Centr.

- number = 1
- size = 1 1/2" x 1" - 7" (1,750)
- motor hp = 1

EDUCTORS: number required = 7

CARBON INVENTORY

Adsorption columns = 4.56 x 5 = 22.80 tonnes

Strip columns = 2.28 x 2 = 4.56 tonnes

Total Inventory = 27.36 tonnes

A. CAPITAL COST

BASIS

M & A mine/mill cost index = 850
Estimate accuracy = ANSI Class I
Escalation = nil

| Item | Specifications | No. | Cost Can. $ | Hp Instal | Hp Op |
|---|---|---|---|---|---|
| Adsorption columns | 3.0m Dx6.5m, carbon steel | 5 | 44,200 | -- | -- |
| Strip column | 1.4m Dx4.5m, carbon steel | 1 | 8,000 | -- | -- |
| Strip solution tank | 4.0m Dx4.0m, carbon steel | 1 | 7,100 | -- | - |
| Pump box | 1,8m Dx1,8m, carbon steel | 1 | 1,500 | -- | -- |
| Heat exchanger | shell & tube, allowance | 1 | 10,000 | -- | -- |
| Rotary kiln | 24" Dx15',w. coll. + fans | 1 | 60,000 | 3 | 3 |
| Kiln feeder bin | 1.2m Dx2.4m,60° cone,c.s. | 1 | 2,000 | -- | -- |
| Kiln feeder | 4" D x 10' screw | 1 | 1,500 | 1/4 | 1/4 |
| Carbon screen | 48" Sweeco | 1 | 7,500 | 2 1/2 | 2 1/2 |
| Pumps | centrifugal, various | 7 | 22,800 | 46-- | 23 1/2 |
| Eductors | -- | 7 | 5,000 | -- | -- |
| Unidentified | allowance | -- | 20,000 | -- | -- |
| Totals | | | 189,900 | 51 3/4 | 29 1/4 |

TOTAL PLANT COST - for cost table, see next page

T.I.C. Plant = 189,900 x 3.25 = $617,000

Cost of initial carbon = 27.36 x 1,000 x 3.50 = $ 95,800

A. OPERATING COSTS

Summary

| Item | Estimated Cost $/year |
|---|---|
| Supervision | 24,000 |
| Operating labour | 109,200 |
| Labour overhead | 46,300 |
| Maintenance | 36,800 |
| Reagents and Chemicals | 33,200 |
| Operating Supplies | -- |
| Electric power | 8,200 |
| Fuel | 20,900 |
| Assaying | 28,000 |
| | 306,600 |
| Contingency @ 10% | 30,400 |
| TOTAL ANNUAL COSTS | 337,000 |

OPERATING COSTS (continued)

Supervision and Technical

Allow 1/2 of a man @ 448,000/year

Annual cost = 48,000/2 = $24,000

Operating Labour

Allow 1 man/shift, 3 shifts per day @ $13.00/hour

Annual cost = 24x350x13.00 = $109,200

Maintenance

Labour - allow 1/2 man/day @ $15.00/hour

- Annual cost = 4x350x15.00 = $21,000

Materials - Annual cost @ 75% Labour = $15,800

Labour Overhead

Allow 30% of supervision and labour costs.

Annual cost = (24,000 + 109,200 + 21,000) x3 = $46,300

Reagents and Chemicals

Carbon - assume 20% of carbon is replaced each year.

- Carbon inventory = 22.80 + 4.56 = 27.36 tonnes
- Annual consumption = 27.36 x .2 = 5.47 tonnes
- Annual cost @ 3.50/kg=$5.47 \times 10^3 \times 3.50$ = $19,200

NaOH - assume 50 kg added each day

- Annual Consumption = 350 x 50 = 17,500 kg
- Annual cost @ $0.60/kg=17,400 x .60 = $10,500

Reagents and Chemicals

NaCN - assume 5 kg added each day

- annual consumption = 5 x 350 = 1,750 kg
- annual cost @ $1,97/kg = 1,750 x 1.97 = $ 3,500

Total Annual Cost Reagents and Chemicals

= 19,200 + 10,500 + 3,500 = $33,200

Operating Supplies

Some drums will be required for carbon fines, but probably can use drums in which carbon supplied. Assume no cost.

Electric Power

Annual Consumption = 29.25 x 85 x 7.46 x 24 x 350/.95 = 164,000 kwh

Annual Cost @ 0.05/kwh = 164,000 x 0.5 = $ 8,200

Fuel

Strip Pollution Heating

- Assume the barren strip solution has to be heated an average of 10°C
- Annual heat requirement
  = 17.7 x 10 x 1,440 x 350 x 3.968/.75 = $4,720 \times 10^6$ BTU
- Annual cost @ $2.50/$10^6$ BTU = 4,720 x 2.50 = $ 11,800

Fuel

Charcoal regeneration

- 25% of the charcoal is to be regenerated; assume contains 25% moisture
- wt. charcoal to regenerated - wet = 760 kg/day
  - dry = 570 kg/day

- annual heat requirement
  = $918.27 \times 10^6 + 322.45 \times 10^6$ = $1,241 \times 10^6$ BTU
- annual cost = $1,241 \times 2.50$ = $ 3,100

Space heat - annualent allowance = $ 6,000

Total annual fuel cost = 11,800 + 3,100 + 6,000 = $20,900

Assaying

Assume 10 gold assays each day

Annual cost @ $8.00/assay = 10 x 350 x 8 $28,000

B DESIGN CRITERIA

Design based on use of Canmet's continuous IX systems with down flow elution.

Adsorption

- resin = IRA 400
- number stages = one
- resin depth, at rest = 3.0 m
- resin expansion during loading = 100%
- leach solution flow rate = 200 lpm/$m^2$
- max. vol. resin advance = 10% resin in column
- frequency resin advance = 1 hour intervals(3 hr/col)
- method resin advance = eductors
- temperature = ambient
- impurities in leach solution = low
- gold assay resin - eluted = 12 gpl wsr.
  - loaded = 66 gpl wsr.
- gold recovery = 98%

Elution

- number stages = 1
- eluant - NaSCN = 4.88 molar
  - dimethylformamide = 50% v/v
- min. resin depth, at rest = 3.0 m
- resin expansion during elution = nil
- eluant flow rate = 50 lpm/$m^2$
- temperature = 50°C
- gold assay - eluant = 0.1 gpl
  - eluate = 5.0 gpl
- frequency resin advance = 1 hour intervals
- min. resin retention time = 2 hours

Washing

- number stages = 1
- wash solution - composition = water
  - flow rate = 40 lpm/$m^2$
  - volume = 4 displacements
- column - capacity = 6 advances
  - diam. = as strip
- resin expansion during wash = 10%
- intermittent operation; no gold loss

Resin regeneration = to be established

B. FLOW CALCULATIONS

| | |
|---|---|
| Leach solution | = as Case A |
| Adsorption gold | |
| - daily wt. in leach soln. = 6,192x3 | = 18,576 gm |
| - daily wt. to resin = 18,576x.98 | = 18,204 gm |
| Adsorption resin & columns | |
| - daily volume loaded = 18,204/(66-12) | = 337 litres (wsr) |
| - column area required = 4,300/200 | = 21.5 $m^2$ |
| - for max. column diam. of 3.0 m, number of columns = 21.5/7.07 | = 3 |
| - flow to each column = 4,300/3 | = 1,434 lpm |
| - resin inventory - column = 3x7.07 | = 21.2 $m^3$ |
| - total = 21.2x3 | = 63.6 $m^3$ |
| - vol. resin per advance = 337/8x3 | = 14 litres |
| Elution solutions | |
| - daily volume = 18,204/(5.0-0.1) | = 3,715 litres |
| - design flow rate = 3,715/1,440x.93 | = 2.8 lpm |
| Elution resin and columns | |
| - column dimensions- area = 2,8/50 | = 0.056 $m^2$ |
| - dia. = 0.056x4/ | = 0.27 m |
| - vol. resin per advance = as adsorption | = 14 litres |
| - resin vol. @ 3.0 m = 0.056x3x1000 | = 168 litres |
| - resin retention time = 168/14 | = 12 hours |

Wash water and columns

- vol. resin in column = 14x6 = 84 litres
- column - diam. as strip = 0.27 m
  - area as strip = 0.056 $m^2$
- wash water per advance
  - total vol.=14x.4x4 = 23 litres
  - flow rate = 0.056x40 = 2.3 lpm
- time per wash = 23/2.3 = 10 minutes

B. EQUIPMENT CALCULATIONS

Pregnant Solution Pond: as Case A

Adsorption Column Feed Hoppers

Design capacity: 14 x 2 = 28 litres = 0.03 $m^3$

$D^2 \times D/3x4=0.03$

D = 0.03x12/ = 0.5 m

Specs: - diam = 0.5 m
- height = 0.5 m
- materials = polyethylene

Adsorption Columns

Design: - diam. = 3.0 m
- area = 7.07 $m^2$
- resin height - at rest = 3.0 m
- expanded = 3x2 = 6.0 m

Specs: - number = 3
- diam. = 3.0 m
- height = 0.5+6.0+0.3 = 66.8 m
- material = carbon steel

Barren Solution Pump Box: as Case A

Eluant and Eluate Tanks

Design capacity @ 4 hours = 2.8x60x4/1,000 = 0.67 $m^3$

D = 0.67x4/ = 0.95 m

Specs: - diam = 1.0 m
- height = 0.95+0.2 = 1.0 m
- materials = carbon steel

Elution Column

Design: - diam. = 0.27 m
- resin depth = 3.0 m

Specs:- diam. = 0.3 m
- height=0.6+3.0+0.3 = 3.9 m
- materials = carbon steel

Wash Column

Design: - diam. = 0.27 m
- resin height- at rest = 1.5 m
- expanded=1.5x1.10 = 1.7 m

Specs:- diam. = 0.3 m
- height=0.5+1.7+0.3 = 2.5 m
- materials = carbon steel

Regeneration Equipment: to be established

Pumps

| | Adsorption Feed | Barren | Eluant |
|---|---|---|---|
| Design cap.,USGPM | 4,300x1.25/3.785=1,400 | as ads. feed=1,400 | 2,8x1.25/3.785= 1 |
| Design head,ft.$H_2O$ | = 60 | = 40 | =40 |
| Specs - style | horz. centr. | horz. centr. | horz. centr. |
| - size | 8"x6"-13" | 8"x6"-12" | 1 1/2"x1"-4" |
| - number w. spare | 2 | 2 | 4 |
| - motor hp, total | 10x2=20 | 7.5x2=15 | 0.5x4=2 |

| | Eluate | Eductor Soln. |
|---|---|---|
| Design cap.,USGPM | as eluant = 1 | estimate = 20 |
| Design head,ft.$H_2O$ | = 30 | = 50 |
| Specs - style | horz. centre. | horz. centre. |
| - size | 1 1/2"x1"-4" | 1 1/2"x1"-7" |
| - number w. spare | 2 | 1 |
| - motor hp, total | 0.5x2=1 | 1 |

Eductors: number required = 5

Resin Inventory

| | | |
|---|---|---|
| Adsorption columns | = 7.07x3.0x3 | = 63.63 $m^3$ wsr |
| Elution column | = x0.$3^2$x3/4 | = 0.21 $m^3$ wsr |
| Wash column | = x0.$3^2$x1.5/4 | = 0.11 $m^3$ wsr |
| Total inventory | | = 63.95 $m^3$ wsr |

B. CAPITAL COST

Basis: as Case A

Equipment Costs

| Item | Specifications | No. | Cost Can. $ | Hp Instal | |
|---|---|---|---|---|---|
| Feed hopper | 0.5m Dx0.5m cones | 3 | 1,500 | -- | -- |
| Adsorption columns | 3.0m Cx6.8m, carbon steel | 3 | 30,600 | -- | -- |
| Elution column | 0.3m Dx3.9m, carbon steel | 1 | 1,500 | -- | -- |
| Wash column | 0.3m Dx2.4m, carbon steel | 1 | 1,000 | -- | - |
| Pump box | 0.3m Dx2.4m, carbon steel | 1 | 1,500 | -- | -- |
| Eluant & eluate tanks | 1.0m Dx1.0m, carbon steel | 2 | 1,500 | -- | -- |
| Regeneration equipment | allowance | -- | 20,000 | 1 | 1 |
| Pumps | centrifugal, various sizes | 9 | 27,600 | 39 | 20 1/2 |
| Eductors | -- | 5 | 2,900 | -- | -- |
| Heat exchanger | allowance | 1 | 5,000 | -- | -- |
| Resin screen | sieve bend, 4'x6' | 1 | 8,500 | -- | -- |
| Unidentified | @ 12% | -- | 12,000 | -- | -- |
| Totals | | 26 | 113,600 | 40 | 21 1/2 |

Total Plant Cost

T.I.C. plant = 113,600 x 3.75 $426,000

Cost initial resin = 63.95x35.31x305.20 $689,200

B. OPERATING COSTS

Summary

| Item | Estimated Cost $/year |
|---|---|
| Supervision | 24,000 |
| Operating labour | 54,600 |
| Labour overhead | 29,900 |
| Maintenance | 36,800 |
| Ion exchange resin | 69,100 |
| Chemicals | 184,800 |
| Electric power | 6,000 |
| Fuel | 6,400 |
| Assaying | 28,000 |
| | 439,600 |
| Contingency | 35,400 |
| Total annual costs | 475,000 |

Note: The above estimates do not include any resin regeneration costs.

B. OPERATING COSTS (continued)

Supervision & Technical

Annual cost = as Case A = $24,000

Operating labour

Allow 1/2 man/shift, 3 shifts/day @ 13.00/hr
Annual cost = 8x3x350x13.00/2 = $54,600

Maintenance

Labour - allow 1/2 man/day @ $15.00/hr
- annual cost = 8x350x15/2 = $21,000
Materials - annual cost @ 75% labour = $15,800
$37,800

Labour Overhead

Annual cost @ 30% supervision and labour
= (24,000+54,600+21,000)x.3 $29,900

Ion Exchange Resin

Assume 10% of resin (IRA 400) is replaced each year
Annual cost = 64.13x0.1x305.20 = $69,100

Chemicals

Assume 5% loss of chemicals in eluant
Annual vol. eluant = 3,715x350 = $1,30 \times 10^6$ litres
Reagent concentrations in eluant
- NaSCN @ 4.88 molar = 4.88x97.17 = 474 gpl
- Dimethylformamide (DMF) = 50% v/v

Annual consumptions
- KSCN = $1.30 \times 10^6$x474x0.5/1,000 = 30,810 kg
- DMF = $1.30 \times 10^6$x.5x.95x.05 = 30,876 kg

Annual costs: - NaSCN @ \$4.10/kg=30,810x4.10 = \$126,300
- DMF @ \$1.895/kg =30,875x1.895 = 58,500
\$184,800

Electric Power

Annual consumption = 21.5x.85x.746x24x350/.95 = 120,000 kwh
Annual cost = 120,000x.05 = \$6,000

Fuel

Process: - assume eluant has to be heated $20^o$
- annual heat requirement
= $1.30 \times 10^6$x20x3.968/.75 = $138 \times 10^6$ BTU
- annual cost = 138x2.50 = \$ 400
Space heat - annual cost as Case A = \$6,000
Total annual fuel cost = \$6,400

Assaying
Annual cost = as Case A = \$28,000

C. DESIGN CRITERIA

Design based on use of Canmet's continuous IX system, with upflow elution

Adsorption

- as for Case B except as noted below
- gold assay elution resin = 6 gpl

Electroelution

- number stages = 1
- eluant - NaOH = 10 gpl
  - NaCN = 1 gpl
  - $Zn(CN)_2$ = 10 gpl
- min. resin depth, at rest = 3.0 m
- resin expansion during elution = 10%
- eluant flow rate = 40 lpm/$m^2$
- temperature = ambient
- gold assays - eluant = 0.002 gpl
  - eluate = 0.200 gpl
- electrolysis power - voltage = 2.5 volts
  - current = 200 amps (for costing only)
- steel wool requirement = 0.2 kg/kg Au
- weight gold to each refining = 30,000 gm
- min. resin retention time = 24 hours
- frequency resin advance = 1 hour intervals

Washing

- number stages = 1
- wash solution - composition = water
  - flow rate = 40 lpm/$m^2$
  - volume = 3 displacements
- column - capacity = 6 advances
  - diam. = as strip
- resin expansion during wash = 10%
- intermittent operation, no gold loss

Resin regeneration = to be established

C. FLOW CALCULATIONS

Leach solution = as Case A

Adsorption gold = as Case B

- daily vol. resin loaded = 18,204(60) = 304 litres
- vol. resin per advance = 304/8x3 = 13 litres
- other weights, volumes and flows as Case B

Elution solutions

- daily vol. = 18,204 (198) = 91,940 litres
- design flow rate = 91,940/1,440x.93 = 67 lpm

Elution resin and colums

- column dim. - area = 67/40 = 1.68 $m^2$
  - diam.= 1.68x4/ = 1.46 m
- vol. resin per advance = 13 litres
- resin vol. @ 3.0 m = 1.68x3.0x1,000 = 5,040 litres
- resin retention time = 5,040/13 = 388 hours

Electrolysis

- gold plated per batch = 30,000 gm
- steel wool per batch = 30,000x.2/1,000 = 6 kg

Wash water and columns

- vol. resin in column = 13 x 6 = 78 litres
- other flows and dimensions as Case B

C. EQUIPMENT CALCULATIONS

Equipment specifications as for Case B except as noted below

Electroelution Column

Specs:

| | |
|---|---|
| - diam - lower section | = 1.5 m |
| - upper section | = 1.8 m |
| - height - lower section | = 2.8 m |
| - upper section | = 1.7 m |
| - anodes & cathodes | = t.b.c. |
| - materials - column | = carbon steel |
| - anodes | = 316 stainless steel |
| - cathodes | = steel wool on 316 ss frame |
| - numbers - column | = 1 |
| - electrode assemblies | = 2 |

Note: Two or more columns may be more practical than one;
a circular electrode configuration may be the most efficient.

Rectifier

| | | |
|---|---|---|
| Specs: - input | - type | = A.C. |
| | - voltage | = 220 volts |
| - output | - type | = D.C. |
| | - voltage | = 2.5 volts |
| | - current | = 200 amps |

Eluant Tank

Design capacity @ 4 hours: 67 x 60 x 4/1,000 = 16.1 $m^3$

D = 16.1 x 4/ 2.74 m

Specs: - diam = 2.8 m
- height = 2.8+0.2 = 3.0 m
- materials = carbon steel

Pumps

| | Adsorption Feed & Barren | Eductor Soln. | Eluant |
|---|---|---|---|
| Design cap. USGPM | | | 67 x 1.25/3.785 = 22 |
| Design head, ft $H_2O$ | | | = 60 |
| Specs - style | as Case B | as Case A | horz. centr. |
| - size | | | 1 1/2" x 1" - 8" |
| - number w. spare | | | 2 |
| - motor hp, total | | | 1 1/2" x 2 = 3 |

Eductors: number required = 4

Recovery of Gold by Single Stage Deep Fluidized Bed,
Ion Exchange and Carbon Technique

Resin Inventory

| | |
|---|---|
| Adsorption columns = as Case B | = 63.63 $m^3$ wsr |
| Elution column = x 1.27 + 4.42 | = 5.69 $m^3$ wsr |
| Wash column = as Case B | = 0.11 $m^3$ wsr |
| Total inventory | = 69.43 $m^3$ wsr |

C. CAPITAL COST

Basis: as Case A

Equipment Costs

| Item | Specifications | No. | Cost Can. $ | Hp Instal | Hp Op |
|---|---|---|---|---|---|
| Feed hoppers | as Case B | 3 | 1,500 | -- | -- |
| Adsorption columns | as Case B | 3 | 30,600 | -- | -- |
| Electroelution column | 1.5to1.8m Dx4.5;electr.ass. | 1 | 15,400 | -- | -- |
| Rectifier | 2.5Vx200amp DC output | 1 | 1,500 | 1 | 1 |
| 1Wash column | as Case B | 1 | 1,000 | -- | -- |
| Eluant tank | 2.8m Dx3.0m | 1 | 3,900 | -- | -- |
| Pump box | as Case B | 1 | 1,500 | -- | -- |
| Pumps | centrifigal, various sizes | 7 | 23,000 | 39 | 20 |
| Eductors | -- | 4 | 2,400 | -- | -- |
| Resin screen | as Case B | 1 | 8,500 | -- | -- |
| Regeneration equipment | allowance | -- | 20,000 | 1 | 1 |
| Unidentified | @ 12% | -- | 13,000 | -- | -- |
| Totals | | 23 | 122,300 | 41 | 22 |

Total Plant Cost

T.I.C. Plant: 122,300 x 3.75 = $458,000

Cost initial resin: 69.43 x 35.31 x 305.20 = $748,200

C. OPERATING COSTS

Summary

| Item | Estimated Cost $/year |
|---|---|
| Supervision | 24,000 |
| Operating labour | 72,800 |
| Labour overhead | 35,400 |
| Maintenance | 37,800 |
| Ion exchange resin | 74,800 |
| Chemicals | 56,000 |
| Electric power | 6,200 |
| Fuel | 6,000 |
| Assaying | 28,000 |
| Operating supplies | 4,200 |
| | 345,200 |
| Contingency @ 10% | 34,800 |
| Total annual costs | 380,000 |

C. OPERATING COSTS (continued)

Supervision & Technical

Annual cost = as Case A = $24,000

Operating labour

Allow 2/3 man/shift, 3 shifts/day @ 13.00/hr

Annual cost = 8x3x350x13.00x 2/3 = $72,800

Maintenance

Annual cost = as Case B = $37,800

Labour Overhead

Annual cost @ 30% supervision and labour

= (24,000+72,800+21,000)x.3 $35,400

Ion Exchange Resin

Assume 10% of resin (IRA 400) is replaced each year

Annual cost = $69.43 \times 35.31 \times .1 \times \frac{305.20}{}$ = $74,800

Recovery of Gold by Single Stage Deep Fluidized Bed,
Ion Exchange and Carbon Technique

Chemicals

| | | |
|---|---|---|
| Assumed daily additions - | NaOH | = 50 kg |
| | - NaCN | = 5 kg |
| | - $Zn(CN)_2$ | = 50 kg |

Annual consumptions

| | |
|---|---|
| - NaOH : 50 x 350 | = 17,500 kg |
| - NaCN : 5 x 350 | = 1,750 kg |
| - $Zn(CN)_2$: 50 x 350 | = 17,500 kg |

Chemicals

Annual costs:

| | |
|---|---|
| - NaOH @ \$0.60/kg = 17,500 x .60 | = \$ 10,500 |
| - NaCa @ \$1.97/kg = 17,50 x 1.97 | = 3,500 |
| - $Zn(CN)_2$ @ \$2.40/kg= 17,500 x 2.40 | = 42,000 |
| Total: | = \$ 56,000 |

Electric Power

| | |
|---|---|
| Annual consumption = 22x.85x.746x24x350/5 | = 123,400 kwh |
| Annual cost @ \$0.05/kwh= 123,400 x .05 | = \$ 6,200 |

Fuel

No process fuel is required

Annual space heat cost = as Case A = 6,000

Assaying

Annual cost = as Case A = $28,000

Operating Supplies

Steel wool:

annual consumption = 18,204x350x.2/1,000 = 1,274 kg

annual cost @ $3.25/kg = 1.274 x 3.25 = $4,200

## 7. CONCLUSIONS

The single stage deep fluidized bed ion exchange column can be adapted for the recovery of gold from cyanide solution.

The following conclusions can be drawn from the testwork conducted:

* The ion exchange column assembly in its present form is not suitable for operation with carbon at the size (6 x 16 mesh) it is used in conventional carbon adsorption operations. It is also not suitable for operation with hard, coarse resin, such as Duolite A-7. The reason is the difficulty on transfering the carbon at a coarse size and prevention of valve closing.

  This can be overcome by using carbon at a finer size and replacement of valves more suited to the operation. In the resin-feed assembly on top of the adsorption column, directed flushing should rectify valve closure problems.

* Of the materials tested in the program, the weak base resin. Duolite A-7 had too low an adsorption capacity for gold to warrant larger scale testing. Amberlite IRA 400 had excellent adsorption capacity for gold from cyanide solutions, when other metal ions such as Cu, Ni, Fe and Zn, were not present. Its adsorption capacity for gold dropped from more than 69 g/L WSR to 1 g/L WSR when those metal ions were present, in the Campbell Red Lake Mines pregnant solution.

Both Calgon GRC 22 and Haycarb YAO showed good adsorption capacity for gold from synthetic solution. Calgon GRC 22 loaded to 18 g/L at the breakthrough point and Haycarb YAO to 22 g/L WSC.

With other metal ions present, gold loading of GRC 22 dropped to 1.2 g/L at the 98% recovery point.

* Electro elution worked on both synthetic solution loaded IRA 400 and Calgon GRC 22 and its adaption into the single stage ion exchange column system should be possible without too much difficulty. The novel elution process employing potassium-thiocyanate in dimethylformamide - $H_2O$ solution looks very promising, in that the elution is very rapid and the gold can be recovered as potassium aurocyanide. Although further testwork is needed, the incorporation into a deep fluidized bed ion exchange column system should be possible.

* The conceptual flowsheet development study and design criteria shows the cost for the single stage deep fluidized bed ion exchange column recovery of gold from cyanide solution with strong base resin to be higher than conventional activated carbon recovery. This is entirely due to the present cost of the resin tested (IRA 400).

Since it has been shown, that KSCN elution from IRA 400, loaded from "clean" cyanide solution, is rapid and will provide a saleable product, in the form of potassium - aurocyanide, the system can avoid time consuming desorption and pyrometallurgical recovery of the gold from steel wool.

Recovery of Gold by Single Stage Deep Fluidized Bed,
Ion Exchange and Carbon Technique

It is suggested that the single stage deep fluidized bed ion exchange column be tested in a heap-leach operation producing "clean" pregnant solution.

Alternately, the development of a resin tailored for the adsorption of gold only, would provide a chance for the single stage deep fluidized bed ion exchange column to be tested by the gold mining industry.

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Materials Division

## REFERENCES

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## Energy

energy conservation programs and analyses, thermal insulation design and evaluation, waste heat recovery, building energy systems and monitoring, heat storage systems and materials, thermoelectric generation, combustion technology, burner development, heat transfer analysis, solar systems monitoring, National Solar Test Facility, solar technology, wind power, coal, lignite and oil sands processing, alternate fuel utilization, battery and fuel cell technology, peat processing and utilization, fenestration measurements, heat pump development and test facilities, residential heating systems, air to air heat exchange test facility, photovoltaic devices, . . .

## Environment

ambient air quality assessment, environmental impact assessments, long-range transport of atmospheric pollutants, precipitation chemistry, particulate characterization studies, emission inventories, source sampling, odour emission and control, asbestos measurement and control, occupational health and safety studies, diesel emission control technology, air pollution control, pesticide residues, trace metal analysis, trace organic analysis, radionuclide analysis, mutagenic testing, noise and vibration analysis, radiation measurements, particulate identification and measurement, water surveys, water purification, industrial and municipal wastewater treatment, membrane separation techniques, wet oxidation, solid waste treatment and recovery, hazardous waste treatment and disposal, indoor air quality assessments, priority pollutant analysis, landfill technology, . . .

## Materials

building materials, plastics, composites, metals, glass and ceramics, wood and wood composites, biomaterials, adhesives and printing inks, fibres, yarns, fabrics and geotextiles, leather, organic and inorganic chemicals, specification development, quality assurance, mechanical, chemical and thermal properties, test method development, failure analysis, fire and flammability, glass-metal seals, metal and alloy powders, metallography, materials characterization, materials characterization by optical and electron microscopy and X-ray microanalysis, photovoltaic materials, materials corrosion resource centre, corrosion properties and control, bacterial corrosion, coatings and sealants, rubber technology, X-ray analysis, cement and concrete, soils and aggregates, gypsum, body armour testing, footwear, paper-making materials, roofing and waterproofing, waste material stabilization and solidification, . . .

## Products & Processes

clothing, footwear and industrial textile products, knitting technology, thin and thick film systems, microelectronics development, fibre optics, instrumentation, bioengineering, ultrasonic and fluid shear devices, microwave drying, transportation and equipment testing, mathematical stress and vibration analysis, product, equipment and machinery design & development, fuel emulsification, organic analysis and characterization, chemistry of foodstuffs, pulp and paper processes, ceramics processing, metallurgical process development, powder metal technology, packaging applications, technical and economic evaluations, industrial engineering applications, process control, enzyme analysis, electrical testing, radioactive surveys, industrial microbiology, biotechnology, technical and management skills development seminars, paper products, absorbent consumer products, detergent and cosmetic formulation, metal chemical analysis, flash hydropyrolysis of coal, electroplating, . . .

## Resources

mineral processing, hydro and pyrometallurgical processing of ferrous and non-ferrous ores, coal evaluation, coal ash utilization and product development, asbestos processing and applications, non-metallic minerals/industrial minerals processing and utilization, uranium processing, forest utilization, utilization of forest and agricultural wastes, utilization of industrial, mining and domestic wastes, energy and chemicals from biomass, in-plant waste reduction, mineralogical services, mining and metallurgical waste disposal, . . .

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